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MAINTAINABILITY ENGINEERING DESIGN NOTEBOOK, REVISION II, AND COST OF MAINTAINABILITY

MARTIN MARIETTA AEROSPACE

PREPARED FOR
ROME AIR DEVELOPMENT CENTER

JANUARY 1975

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The RADC Maintainability Engineering Design Notebook brings together currently available knowledge of maintainability engineering and treats such knowledge from a practical rather than theoretical viewpoint. The notebook provides both quantitative and qualitative information and techniques which can serve as guidelines for those personnel who are directly responsible for establishing maintainability requirements and maintainability design, and for the acceptance of the maintainability of Air Force ground electronic systems

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and equipments.

Although the notebook is directed at ground electronic systems, the majority of the material is applicable to a much broader class of hardware.

Specifically, the notebook includes a description of the time phasing of the maintainability program tasks, a breakdown of maintainability into its roots, and detailed description, guidelines and methodology, procedures, and an example of each maintainability task, as applicable.

Since maintainability covers a wide range of disciplines ranging through electronic and mechanical design, instrumentation requirements, logistic support, personnel requirements, and statistics, it is not anticipated that any single group will find all of its responsibilities completely described in this notebook. It should, however, contribute significantly to improved maintainability programs and subsequent improved system/equipment maintainability.

It is intended that the notebook will be updated and revisions issued as necessary to enhance its applicability and maintain its currency with advances in the maintainability discipline.

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MAINTAINABILITY ENGINEERING DESIGN NOTEBOOK, REVISION II, AND COST OF MAINTAINABILITY

Lyle R. Greenman

Martin Marietta Aerospace Corporation

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FOREWORD

This three volume final technical report was prepared by Martin Marietta Aerospace Corporation, Orlando, Florida under Contract F30602-73-C-0201, Job Order Number 55190123 for Rome Air Development Center, Griffiss Air Force Base, New York. It was prepared in accordance with the format requirements set forth in AFSC Design Handbook DH 1-1, General Index and Reference. The format permits updating of the notebook as new methods and information become available.

RADC Project Engineer was James Saporito, Jr. (RBRS).

This notebook is dedicated to Mr. Frank Mazzola whose untimely death resulted in a great loss to the maintainability world.

This report has been reviewed by the Office of Information (OI), RADC, and approved for release to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This report has been reviewed and is approved for publication.

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ABSTRACT

The RADC Maintainability Engineering Design Notebook brings together currently available knowledge of maintainability engineering and treats such knowledge from a practical rather than theoretical viewpoint. The notebook provides both quantitative and qualitative information and techniques which can serve as guidelines for those personnel who are directly responsible for establishing maintainability requirements and maintainability design, and for the acceptance of the maintainability of Air Force ground electronic systems and equipments.

Although the notebook is directed at ground electronic systems, the majority of the material is applicable to a much broader class of hardware.

Specifically, the notebook includes a description of the time phasing of the maintainability program tasks, a breakdown of maintainability into its roots, and detailed description, guidelines and methodology, procedures, and an example of each maintainability task, as applicable.

Since maintainability covers a wide range of disciplines ranging through electronic and mechanical design, instrumentation requirements, logistic support, personnel requirements, and statistics, it is not anticipated that any single group will find all of its responsibilities completely described in this notebook. It should, however, contribute significantly to improved maintainability programs and subsequent improved system/equipment maintainability.

It is intended that the notebook will be updated and revisions issued as necessary to enhance its applicability and maintain its currency with advances in the maintainability discipline.

EVALUATION

1. The objective of this effort was to provide for the revision and expansion of the RADC Maintainability Design Engineering Notebook, RADC-TR-69-286; and to develop quantitative relationships capable of equating desired values of maintainability to values of cost.

2. The Maintainability Notebook brings together currently available knowledge of maintainability engineering and treats it from a practical viewpoint. It provides both quantitative and qualitative information and techniques which serve as guidelines for those who are directly responsible for establishing maintainability requirements and maintainability design of Air Force ground electronic systems and equipments.

3. It further includes detailed breakdowns of program elements and tasks of maintainability specified in AFP 300-7, MIL-STD-470, MIL-STD-471A, MIL-STD-721B and MIL-HDBK-472. It indicates current policy on Integrated Logistics Support (ILS) and its relationship to the various facets of maintainability. It also traces the responsibility of implementing these through the system acquisition phases.

4. The Notebook provides a description of the time-phasing of maintainability program tasks and a breakdown of maintainability into its cost envelope for each task as a function of equipment characteristics.

5. The analysis of the cost of maintainability resulted from data on 17 systems consisting of inputs from 14 companies collected through solicitation and questionnaires. The degree of accuracy of the cost data can only be substantiated through the collection of additional cost data from cooperating electronic companies and compared to the actual costs of systems and their maintenance. This collection and comparison will continue in the house to assure that cost data are reliable and useable.

6. In summary, the Notebook contains a wide spectrum of maintainability knowledge, ranging from management and cost to design. It will provide government and industrial organizations, at all levels, with the necessary knowhow, to specify, generate and apply the maintainability disciplines. The Notebook will be distributed to AFSC, Wright-Patterson AFB OH, where it will be published as a design handbook. It will also be generally distributed through DDC.

7. The Notebook will be continually updated and revisions issued as necessary to enhance its applicability and maintain its currency with advances in maintainability. It is designed such that revisions and new chapters can be inserted without affecting the basic format.

JAMES SAPORITO
Rel. & Maint. Engineering Section
Reliability Branch

CONTENTS

CHAPTER 1	- MAINTAINABILITY PROGRAM INTRODUCTION	1
CHAPTER 2	- ROOTS OF MAINTAINABILITY	82
CHAPTER 3	- MAINTAINABILITY PROGRAM PLAN	128
CHAPTER 4	- DESIGN REVIEW	163
CHAPTER 5	- MAINTAINABILITY ALLOCATIONS	204
CHAPTER 6	- MAINTAINABILITY REPORTS	227
CHAPTER 7	- TRADE-OFFS	251
CHAPTER 8	- SPECIAL MAINTAINABILITY ANALYSIS	342
CHAPTER 9	- MAINTAINABILITY MODEL	363
CHAPTER 10	- MAINTENANCE CONCEPT	458
CHAPTER 11	- GOVERNMENT FURNISHED EQUIPMENT (GFE) INTEGRATION	501
CHAPTER 12	- MAINTAINABILITY DESIGN CRITERIA AND SPECIFICATION INPUTS	507
CHAPTER 13	- MAINTAINABILITY PREDICTIONS	548
CHAPTER 14	- MAINTAINABILITY DESIGN AUDIT	659
CHAPTER 15	- MAINTAINABILITY DEMONSTRATION PLAN	665
CHAPTER 16	- MAINTAINABILITY DEMONSTRATION CONDUCT AND REPORT	884
CHAPTER 17	- MAINTAINABILITY DATA COLLECTION, ANALYSIS, AND CORRECTIVE ACTION	984
APPENDIX A	- ABBREVIATIONS AND DEFINITION OF TERMS	A-1
APPENDIX B	- BASIC MATHEMATICAL AND STATISTICAL CONCEPTS	B-1
APPENDIX C	- STATISTICAL TABLES	C-1
APPENDIX D	- THE LOGNORMAL DISTRIBUTION	D-1
APPENDIX E	- SYSTEM ACQUISITION PROCESS SUMMARY	E-1
APPENDIX F	- THE STRUCTURE OF AIR FORCE MAINTENANCE AND THE AIR FORCE MAINTENANCE ORGANIZATION	F-1

CHAPTER 1

MAINTAINABILITY PROGRAM INTRODUCTION

This chapter describes the contents and purpose of the Maintainability Engineering Design Notebook. It also identifies the military and other documents that supplement the notebook and indicates the portions of the notebook to which these documents apply. The maintainability program is presented by means of text and a maintainability program "roadmap." The chapter concludes by presenting characteristics of a sample system that will be used to illustrate many of the notebook procedures.

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CHAPTER 1 MAINTAINABILITY PROGRAM INTRODUCTION

SECTION 1A - PURPOSE AND USE OF NOTEBOOK

Design Note 1A1 - Notebook Application
1A2 - General Philosophy
1A3 - Maintainability Interfaces
1A4 - System Acquisition Process

SECTION 1B - MAINTAINABILITY PROGRAM DESCRIPTION

Design Note 1B1 - Maintainability Program Philosophy
1B2 - Maintainability Program Roadmap
1B3 - Maintainability Related Program Functions
1B4 - Maintainability Task Description
1B5 - Cost of Maintainability Tasks
1B6 - Maintainability Related Support Functions
1B7 - Maintainability Related System Design Data

SECTION 1C - SAMPLE SYSTEM

Design Note 1C1 - The Multiplexer Set

SECTION 1A

PURPOSE AND USE OF NOTEBOOK

This section describes the notebook's scope and purpose. It also summarizes the subjects covered and describes how to use the notebook effectively.

SECTION 1A PURPOSE AND USE OF NOTEBOOK

DESIGN NOTE 1A1 - NOTEBOOK APPLICATION

1. GENERAL
2. PURPOSE
3. SCOPE
4. SUPPLEMENTING DOCUMENTATION
4.1 Military Standards
4.1.1 Maintainability Program Requirements (MIL-STD-470)
4.1.2 Maintainability Demonstration (MIL-STD-471A)
4.1.3 Maintainability Definitions (MIL-STD-721B)
4.2 Military Handbooks
4.3 Air Force Manuals
4.3.1 Systems Engineering Management Procedures (AFSCM 800-XX)
4.3.2 Optimum Repair-Level Analysis (AFSCM 800-4)
4.4 Air Force Technical Reports
4.5 Air Force Regulations
4.6 Air Force Pamphlets

DESIGN NOTE 1A2 - GENERAL PHILOSOPHY

1. WHAT IS MAINTAINABILITY?
2. WHY MAINTAINABILITY?
2.1 System Effectiveness
2.2 Ease of Logistic Support
2.3 Ease of Maintenance
2.4 Summary

DESIGN NOTE 1A3 - MAINTAINABILITY INTERFACES

1. GENERAL
1 (1) Maintainability Program Interfaces
2. MAINTAINABILITY/MAINTENANCE ENGINEERING INTERFACE
2 (1) Maintainability/Maintenance Engineering Task Interface

DESIGN NOTE 1A4 - SYSTEM ACQUISITION PROCESS

1. INTRODUCTION

1 (1) Phases of the Acquisition Process

DESIGN NOTE 1A1 NOTEBOOK APPLICATION

1. GENERAL

The Department of Defense (DoD) has recognized the need to establish Integrated Logistics Support (ILS) as a distinct discipline and has published DoD Directive 4100.35, Development of Integrated Logistics Support Planning for Systems Equipments. This DoD document has been implemented by AFP 800-7, Integrated Logistic Support Implementation Guide for DoD Systems and Equipments. These publications define ILS and essential, related maintainability tasks that must be accomplished during materiel acquisition, but do not prescribe precise methods of accomplishment.

2. PURPOSE

The purpose of this notebook is to present current maintainability policies and currently accepted methods of accomplishing each task defined in MIL-STD-470, Maintainability Program Requirements. It is recognized that wide variations will exist between specific projects in the detailed contractual requirements and the amount of resources available for performance of individual tasks. For this reason, basic principles and sample methods have been presented, along with some variations in procedures, guidelines, and methodology which can be adapted to specific requirements and available resources.

3. SCOPE

The scope of this document includes program elements of maintainability specified in AFP 800-7 and MIL-STD-470. It states the DoD policy on ILS and maintainability, and traces the responsibility of implementing these policies through the system acquisition phases. DN 1B2 contains a maintainability roadmap of program elements and the program phase relationship.

Each chapter contains a description of the task, with guidelines, methodology, and, in most cases, procedures and examples for accomplishing the task. The only exception to this outline is Chapter 2, which describes the roots of maintainability. Starting with Chapter 3, the sequence of the chapters is by task and is the sequence in which they would normally occur in the acquisition of a system.

Although this document is specifically dedicated to the implementation of a maintainability program on a ground electronic system, the philosophies presented are generally applicable to other types of systems.

4. SUPPLEMENTING DOCUMENTATION

Many of the procedures, techniques, and policies that are needed in the system procurement process are published and are in regular use throughout the Air Force. The documents that are required to supplement the notebook are listed below.

4.1 Military Standards

4.1.1 Maintainability Program Requirements (MIL-STD-470) (See Sect 1B.)

The requirements of this standard are applicable to planning and implementing the development phases of all system and equipment acquisitions. When development is not involved, the standard is applicable to the extent specified in the contract documentation.

The specification requires contractors to plan and implement a maintainability program. The specification lists all tasks to be performed and details the specifics of each task.

4.1.2 Maintainability Demonstration (MIL-STD-471A) (See Chap 15 and 16.)

MIL-STD-471A, Maintainability Demonstration, is intended for use in demonstration of maintainability at any hardware level (systems, subsystem, etc.) and at any level of maintenance under any defined set of maintenance conditions.

It includes standard procedures for demonstrating maintainability and a number of test methods. Selection of test methods will be made by the procuring activity directly or by delegation to the selected contractor, and it will be based on acceptable tradeoffs between risk, cost, and time and on the degree to which assumptions underlying specific plans are valid for the situation covered by the procurement.

4.1.3 Maintainability Definitions (MIL-STD-721B)

MIL-STD-721B, Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety, defines words and terms used most frequently in specifying effectiveness to give these terms a common meaning for DoD contractors.

4.2 Military Handbooks

MIL-HDBK-472, Maintainability Predictions, provides information on current maintainability prediction procedures. (See Chap 13.)

4.3 Air Force Manuals

4.3.1 Systems Engineering Management Procedures (AFSCM 800-XX) (See Appendixes E and F.)

The AFSCM 800-XX series of manuals establish the requirements, policies, and procedures for system program office management of the system engineering effort. They are the system engineering management standard for all AFSC system acquisition programs and projects.

These manuals serve two purposes. First, they define a common system analysis process that leads to system definition in terms of performance requirements on a total system basis. Secondly, they provide a detailed "roadmap" of engineering actions in their relative order of occurrence during a system's life cycle.

4.3.2 Optimum Repair-Level Analysis (AFSCM 800-4) (See Chap 7 and 9.)

AFSCM 800-4 explains a repair-level analysis system applicable to AFLC/AFSC organizations. It is a guide for use in procurement of new weapon/support systems and provides contractors and prospective contractors with a basis on which an optimum approach to level of repair or discard at failure can be evolved concurrently with the definition and engineering development of a weapon/support system.

4.4 Air Force Technical Reports

RADC-TR-68-187	Maintainability of Micro Circuit Equipment	(See Chap 9.)
RADC-TR-69-356	Vol I, Maintainability Prediction and Demonstration Techniques	(See Chap 13.)
RADC-TR-69-356	Vol II, Maintainability Prediction and Demonstration Techniques	(See Chap 15 and 16.)
RADC-TR-70-89	Maintainability Prediction and Demonstration Techniques	(See Chap 13.)

4.5 Air Force Regulations

AFR 80-14	Test and Evaluation	(See Chap 15.)

4.6 Air Force Pamphlets

AFP 800-7	Integrated Logistics Support Implementation Guide for DoD Systems and Equipments	(See Appendixes E and F.)
AFSCP 800-3	Guide for Program Management	(See Appendix E.)

DESIGN NOTE 1A2 GENERAL PHILOSOPHY

1. WHAT IS MAINTAINABILITY?

A definition of maintainability adopted by the Department of Defense and the defense industry is as follows: "A characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources" (MIL-STD-721B). In general, maintainability refers to the ease with which equipment can be maintained in an operational condition. It is an attribute of design.

Maintainability, as a measure of the ease and rapidity with which a system or equipment can be restored to operational status following a failure, is a function of equipment design and installation, personnel availability in the required skill levels, adequacy of maintenance procedures and test equipment, and the physical environment under which maintenance is performed.

To be a meaningful value as a design criterion, maintainability must be capable of quantitative expression for specifying, estimating, measuring, and demonstrating its value.

Maintainability can be expressed either as a measure of the time required to repair a given percentage of all system failures, or as a probability of restoring the system to operational status within a given period of time following a failure. Both of these figures of merit will be used in later parts of this notebook.

Several concepts are implied in the definition of maintainability given above:

a. Maintainability is a design characteristic that is built into the equipment and must be considered in the early conceptual phases of a Research and Engineering (R&E) program for new equipment and pursued through each subsequent program phase.

b. Maintainability can be predicted and measured in terms of maintenance man-hours and equated to dollars for inclusion in maintenance cost forecasts.

c. Maintainability must not be treated as an isolated design feature, but as an interface with reliability, equipment availability, and logistic support factors.

d. Maintainability must be a practical design constraint; i.e., the equipment user's maintenance resources and operational environment must be considered without unduly constraining the functional design.

e. The maintainability features designed into the equipment must support the equipment mission.

To summarize, maintainability is concerned with any design and maintenance concept decisions which have an impact on maintenance and its attendant logistics resource requirements. Chapter 2 defines maintainability in terms of its roots.

2. WHY MAINTAINABILITY?

The basic worth of a system to its owner is determined by two fundamental factors: system effectiveness, and ease of logistic support, which includes ease of maintenance. The two factors are dependent, in large measure, on the maintainability characteristics of the system. Maintainability is therefore a critically important consideration in planning the acqusition of a new sytem or equipment.

2.1 System Effectiveness

Reliability, performance capability, and availability are primary measures of system effectiveness. Availability and its several derivations (i.e., turn-around time, operational ready-rate, etc.) are directly proportional to the maintainability characteristics of the system. A system that is quickly maintainable is more often operable at the instant it is needed.

2.2 Ease of Logistic Support

Maintenance requires skilled personnel in quantities and skill levels commensurate with the complexity of the maintenance characteristics of the system. A system that is easily maintainable can be quickly restored to service by the skills of available maintenance personnel. The use of other logistic resources, such as tool and test equipment, facilities, and spare parts stockage, are also optimized in direct proportion to the degree of maintainability designed into a system.

2.3 Ease of Maintenance

A system that is quickly and easily maintained reduces the operating costs throughout its life cycle. This is accomplished by reducing the man-hours and labor skills required for maintaining the system and thereby reducing the amount of training required. These reductions are important when it is considered that life cycle support costs for equipment often range from 3 to 20 times its original procurement cost.

2.4 Summary

Maintainability should not be designed into a system for the sake of maintainability, but rather, the degree of maintainability, like all other design disciplines, should be determined as that representing the system which meets or exceeds the operational requirements at the minimum life cycle cost. It should be pointed out that if the contract is awarded based on lowest acquisition cost alone, one can expect only a design which meets (but not exceeds) the maintainability time requirements and constraints at the minimum acquisition cost. The term "system" as used here means the deployed tactical hardware with all the accompanying support personnel, hardware, and software.

DESIGN NOTE 1A3 MAINTAINABILITY INTERFACES

1. GENERAL

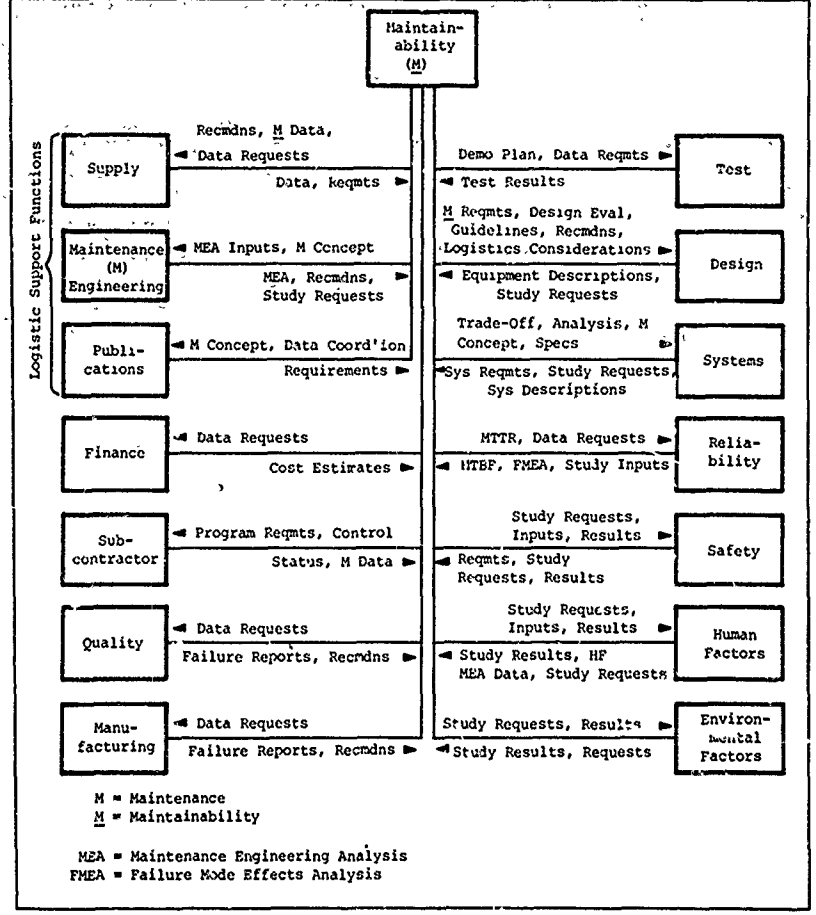
The intricate relationship between maintainability as a system effectiveness parameter and maintainability as a system design attribute is frequently misunderstood. Inadequate consideration of maintainability in the early planning and design phases of material acquisition can result in critical shortages of personnel of the skill levels required to effectively maintain a system, inadequacies in built-in monitoring and fault isolation facilities, deficiencies in test equipment and maintenance provisions, inaccessible locations of high failure rate components, unsafe maintenance conditions, and, as a result, exorbitant life cycle costs.

Maintainability engineering is the system engineering discipline within which the techniques of system analysis and equipment design are combined with a knowledge of reliability, safety, human factors, and life cycle cost methodology, to provide optimization of the maintainability aspects of system design and an awareness of interface problems. The maintainability engineering function involves the formulation of an optimum combination of design features, repair policies, and maintenance resources to achieve a specified level of maintainability at minimum life cycle costs. There are many interfaces and feedback paths between these disciplines. SN 1 (1) depicts the feedback paths and the type of data.

2. MAINTAINABILITY/MAINTENANCE ENGINEERING INTERFACE

The maintenance engineer is primarily system support oriented, whereas the maintainability engineer is primarily system design oriented. This does not in any way imply lack of knowledge of support by the maintainability engineer

SUB-NOTE 1(1). Maintainability Program Interfaces

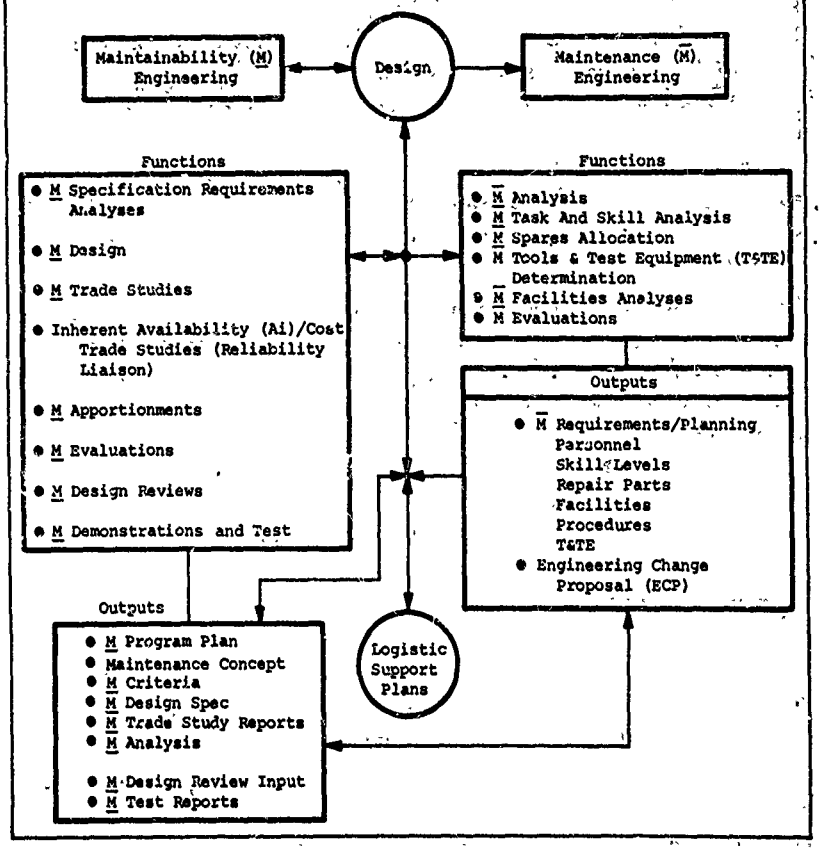


or of design by the maintenance engineer. Their two areas of activity and interest are complementary. Each depends on the other for analysis support and technical data in establishing an optimum and mutually compatible set of design criteria and repair policies.

The maintenance engineer is a specialist in maintenance procedures, task analysis, development of instruction, and determination of resource requirements in terms of personnel and test equipment needed to satisfy the maintainability requirement.

In summary, maintainability engineering is primarily a before-the-act (of design) activity, while maintenance engineering is generally an after-the-fact function. There are, however, many interfaces and feedback paths between the two specialties as depicted in SN 2 (1).

SUB-NOTE 2 (1) Maintainability/Maintenance Engineering Task Interface



DESIGN NOTE 1A4 SYSTEM ACQUISITION PROCESS

1. INTRODUCTION

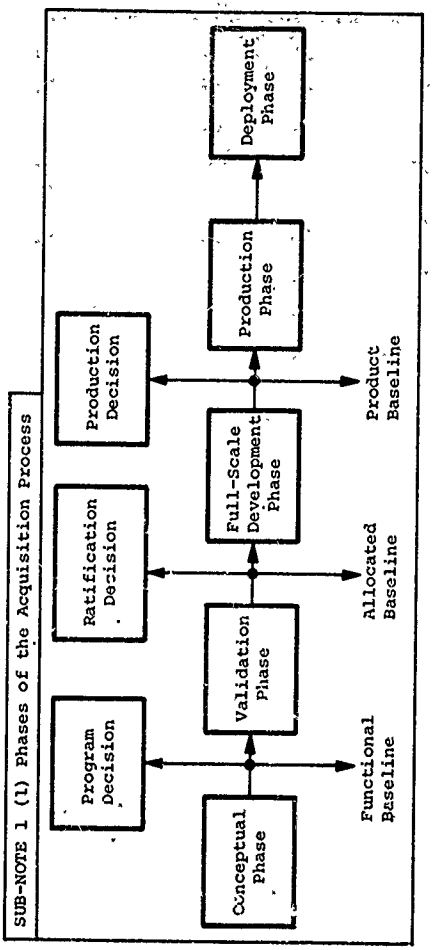
The development of any new system is a complex task that requires interaction among a number of agencies. To achieve proper coordination, the Air Force uses a process of system management called "functional management." It is defined as the process of planning, organizing, coordinating, controlling, and directing Air Force efforts within a structure that groups responsibilities according to type of work. Titles such as plans, programs, research, procurement, supply, maintenance, personnel, intelligence training operations, civil engineering, security, and medical support are descriptive of group responsibilities.

The acquisition process consists of five major phases with major decisions required before proceeding with the second, third, and fourth phases as indicated below and in SN 1 (1). (A more detailed description of the program phases which has been extracted from AFSCP 800-3 is included in Appendix E of this notebook.)

Conceptual Phase - Program Decision
Validation Phase - Ratification Decision
Full-Scale Development Phase - Production Decision
Production Phase
Deployment Phase

The first phase is the Conceptual Phase, during which the technical, military, and economic bases are established, and the management approach is delineated. The Program decision following this phase determines subsequent system progression and establishes the functional baseline.

The second phase is the Validation Phase, during which major program characteristics are validated and refined, program risks are assessed, resolved, or minimized, and the confidence of success becomes high enough to warrant progression to the next phase. It establishes the allocated baseline.


SUB-NOTE 1 (1) Phases of the Acquisition Process
Conceptual Phase
Validation Phase
Full-Scale Development Phase
Production Phase
Deployment Phase
Program Decision
Ratification Decision
Production Decision
Functional Baseline
Allocated Baseline
Product Baseline

The third phase is the Full-Scale Development Phase, during which design, fabrication, and test are completed to assure that the program is ready for the Production Phase, and establishes the product baseline.

The fourth phase is the Production Phase, during which the system is efficiently produced and delivered as an effective supportable system.

The final phase is Deployment, during which the system reaches its operational ready state and is turned over to the using command for transition to the Air Force Logistic Command (AFLC).

SECTION 1B

MAINTAINABILITY PROGRAM DESCRIPTION

This section identifies and describes the maintainability program tasks and the interrelationship of all the factors directly related to maintainability.

SECTION 1B MAINTAINABILITY PROGRAM DESCRIPTION

DESIGN NOTE 1B1 - MAINTAINABILITY PROGRAM PHILOSOPHY

1. GENERAL

1 (1). Maintainability Program Tasks/System Phase Relationships

1 (2) Maintainability (M) Effort Program Phases

DESIGN NOTE 1B2 - MAINTAINABILITY PROGRAM ROADMAP

1. GENERAL

1 (1) Maintainability Roadmap

2. MAINTAINABILITY ROADMAP DESCRIPTION

2.1 Maintainability Related Program Functions

2.2 Maintainability Tasks

2.3 Maintainability Related Support Functions

2.4 Maintainability Related System Design Data

2.5 Maintainability Related Milestones

DESIGN NOTE 1B3 - MAINTAINABILITY RELATED PROGRAM FUNCTIONS

1. REQUIRED OPERATIONAL CAPABILITY (ROC)

2. PROGRAM MANAGEMENT DIRECTIVE (PMD) ISSUED

3. OPERATIONAL CONSTRAINTS AND CONCEPT

4. DEPLOYMENT CONCEPT

5. ANALYZE MAINTAINABILITY AND MAINTENANCE REQUIREMENTS AND ESTABLISH CONSTRAINTS

5.1 Quantitative Constraints

5.1 (1) XYZ Critical Communications Link

5.2 Qualitative Constraints

6. PREPARATION OF SPECIFICATION INPUTS

7. SECRETARY OF DEFENSE (SECDEF) APPROVES DEVELOPMENT CONCEPT PLAN (DCP)

8. FUNCTIONAL BASELINE

9. PROGRAM MANAGEMENT PLAN (PMP)

10. APPROVED DCP

11. ALLOCATED BASELINE

12. APPROVED DCP
13. PHYSICAL CONFIGURATION AUDIT (PCA)
14. PROGRAM DOCUMENTATION UPDATED
15. PRODUCT BASELINE
16. CATEGORY I TEST START
17. CATEGORY II TEST PLAN AND START
18. CATEGORY I AND II TEST
19. CATEGORY III TEST

DESIGN NOTE 1B4 - MAINTAINABILITY TASK DESCRIPTION

1. MAINTAINABILITY PROGRAM PLAN
2. MAINTAINABILITY ALLOCATIONS
3. DESIGN REVIEWS
3.1 Design Concept Review
3.2 Preliminary Design Review
3.3 Critical Design Review
4. MAINTAINABILITY REPORTS
5. TRADE-OFFS
6. SPECIAL MAINTAINABILITY ANALYSIS
7. MAINTAINABILITY MODELING
8. MAINTENANCE CONCEPT
9. MAINTAINABILITY DESIGN CRITERIA AND SPECIFICATION INPUTS
10. MAINTAINABILITY PREDICTIONS
11. MAINTAINABILITY DESIGN AUDIT
12. MAINTAINABILITY DEMONSTRATION
13. MAINTAINABILITY DATA COLLECTION, ANALYSIS, AND CORRECTIVE ACTION

DESIGN NOTE 1B5 - COST OF MAINTAINABILITY TASKS

1. COST ESTIMATORS

(1) 1 Program Plan
(1) 2 Design Review

(1) 3 Allocations
(1) 4 Reports
(1) 5 Trade-Offs
(1) 6 Special Analysis
(1) 7 Models
(1) 8 Maintenance Concept
(1) 9 GFE Integration
(1) 10 Design Criteria and Specifications
(1) 11 Predictions
(1) 12 Design Audit
(1) 13 Demonstration Plan
(1) 14 Demonstration Conduct
(1) 15 Demonstration Report
(1) 16 Data Collection and Analysis
(1) 17 Σ Maintainability Tasks
(1) 18 Σ Demonstration Conduct and Report

DESIGN NOTE 1B6 - MAINTAINABILITY RELATED SUPPORT FUNCTIONS

1. MAINTENANCE ANALYSIS

1.1 General
1.2 Logistic Resources
1.2.1 Equipment Publications (T.O.)
1.2.2 Spares
1.2.3 Facilities
1.2.4 Personnel and Training
1.2.5 Support Equipment
1.2.6 Transportation
1.2.7 Calibration Requirements Summary

DESIGN NOTE 1B7 - MAINTAINABILITY RELATED SYSTEM DESIGN DATA

1. DESCRIPTION

DESIGN NOTE 1B1 MAINTAINABILITY PROGRAM PHILOSOPHY

1. GENERAL

A maintainability program centers around the maintainability tasks and management procedures that will be utilized to control maintainability throughout a system's life cycle. The primary objectives of a maintainability program are as follows:

a. To ensure design adherence in relation to specified operational and performance parameters in consonance with those principles associated with a highly maintainable system.

b. To ensure system design and maintenance concept optimized in terms of lowest life cycle cost.

The efforts of a maintainability program are conducted during all phases of a system's life cycle.

The procuring agency should specify in its acquisition procurement contracts of its Request for Proposal (RFP) the requirement for the conduct of a maintainability program in accordance with a standard procedural or requirement document. The military document which governs all military maintainability program requirements is MIL-STD-470, Military Standard Maintainability Program Requirements for Systems and Equipments.

It is the responsibility of the procuring agency to identify the requirement for a maintainability program and to monitor the contractor's maintainability program; it is the responsibility of the contractor to establish and maintain an effective maintainability program.

The contractor's response to the RFP should be evaluated by the procuring agency to assure that the contractor understands and is responsive to the requirements, and to assure that the contractor has an effective, realistic set of resources and management tools to assure timely attainment of the requirements and demonstration of the attainment.

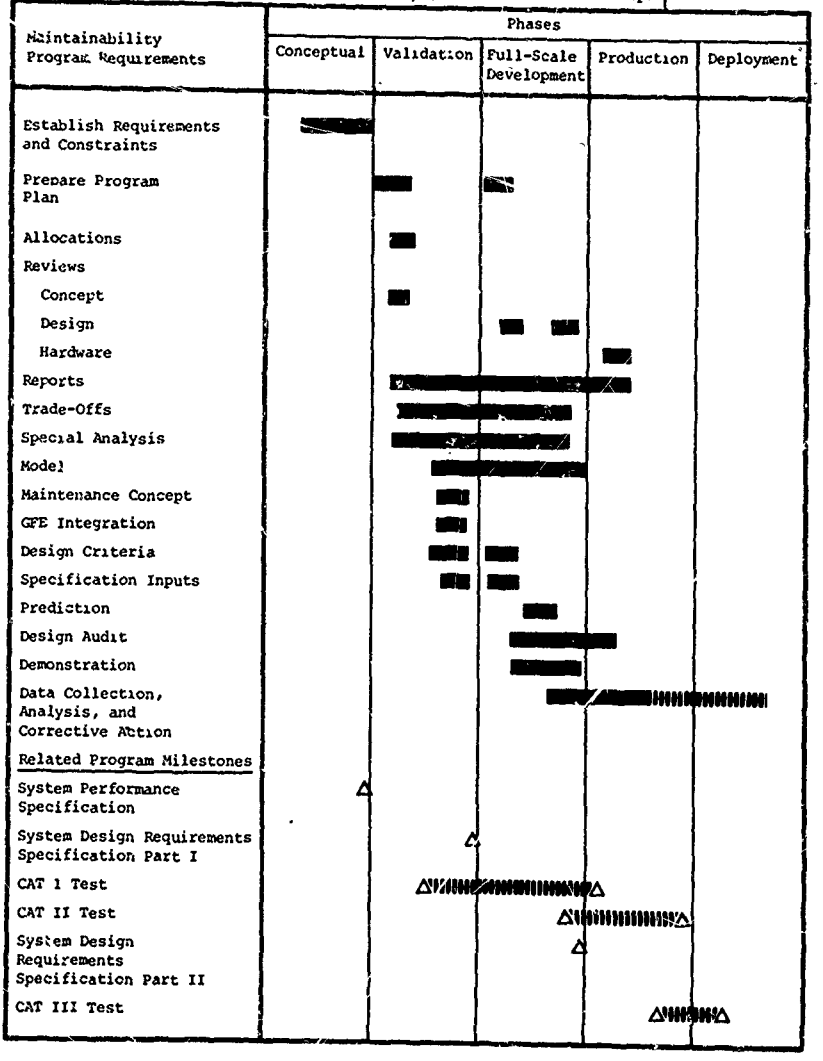
Since MIL-STD-470 is definitive in the tasks of a maintainability program plan, the variation in plans submitted for review should reflect the contractor's understanding of a maintainability program, the system requirements, and the uniqueness of his maintainability organization and techniques for maintainability analysis. The tasks are defined by MIL-STD-470; the "how" reflects the contractor's capability.

The effectiveness of the maintainability effort is defeated unless the efforts within the program are completed in a timely manner in consonance with the overall design engineering milestones. All tasks should be scheduled to be completed in time to be effective in the decision-making process. To be effective, the maintainability organization should be in a position to recognize foreseeable problem areas, identify efforts required to investigate and correct these problems, and be timely with changes within the design phase.

The identification of appropriate procuring agency-contractor program milestone review points is necessary to assure that all aspects of the program development are approved and identifiable problems resolved. These formal maintainability reviews are usually scheduled during the program design reviews, while informal review is established by the procuring agency after review of data elements (i.e., status reports, trade reports, predictions, etc.) throughout the program. The latter is usually devoted to the solution of special problems.

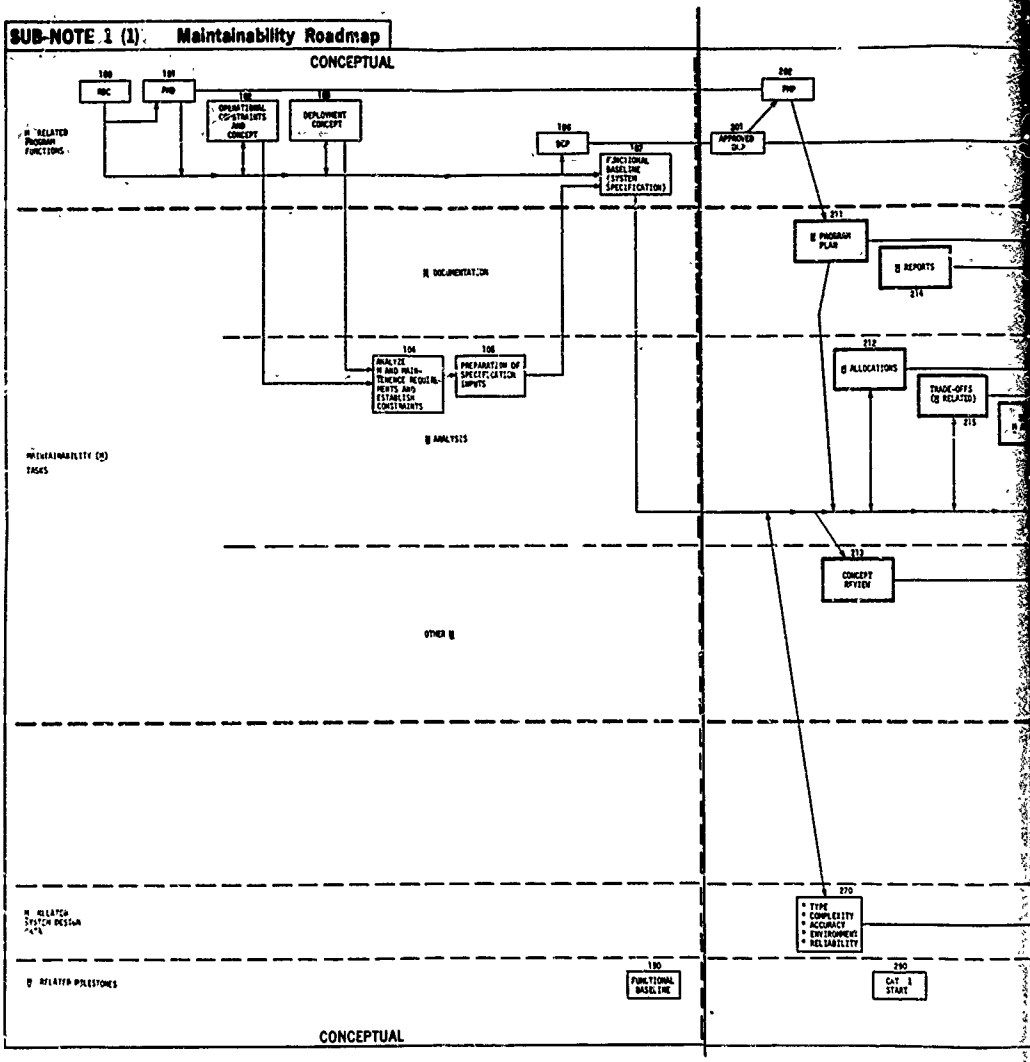
SN 1(1) depicts the maintainability program tasks and time phasing in relation to various phases of the system development cycle. SN 1(2) summarizes the maintainability efforts conducted during each of the phases.

SUB-NOTE 1 (1) Maintainability Program Tasks/System Phase Relationships

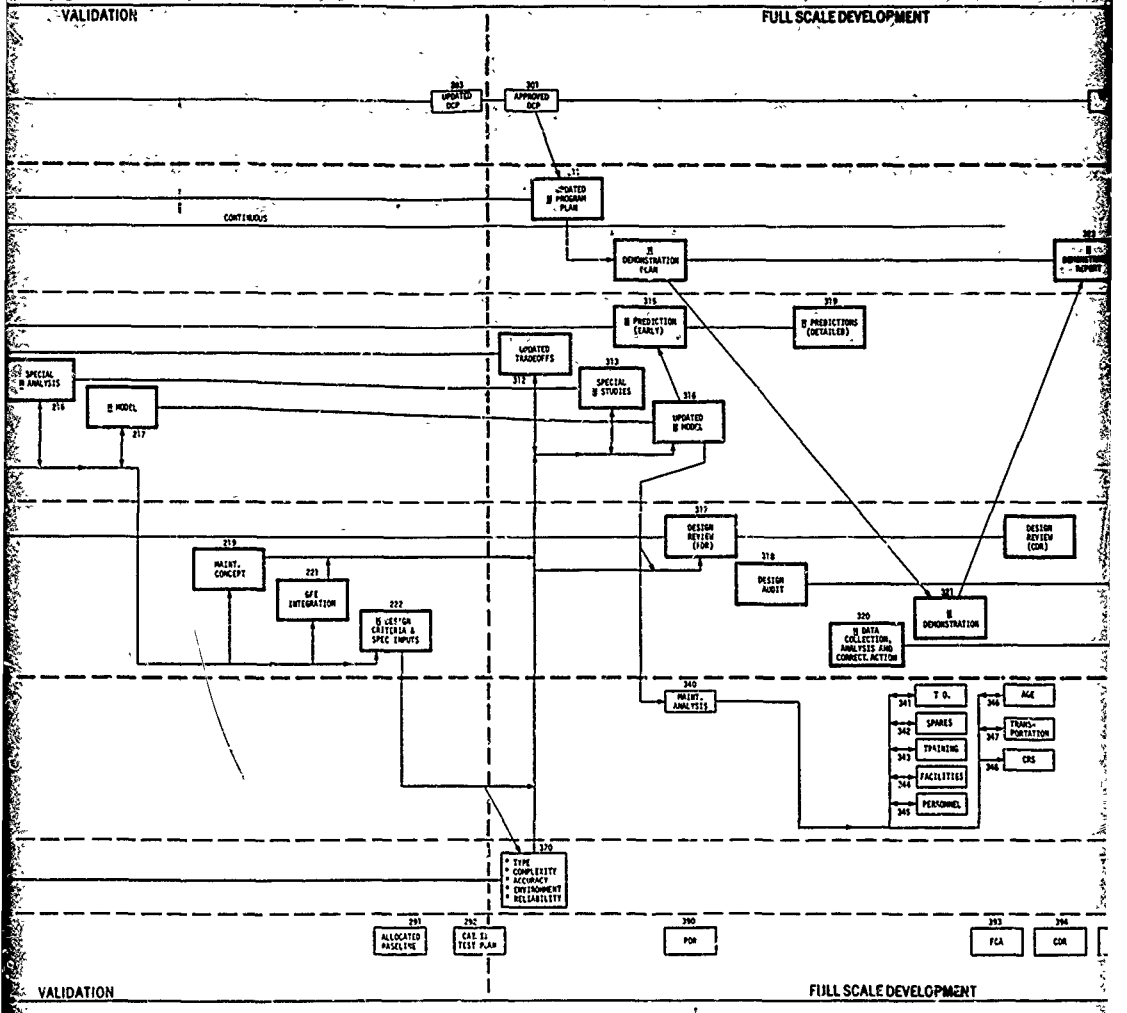


SUB-NOTE 1 (2) Maintainability (M) Effort Program Phases

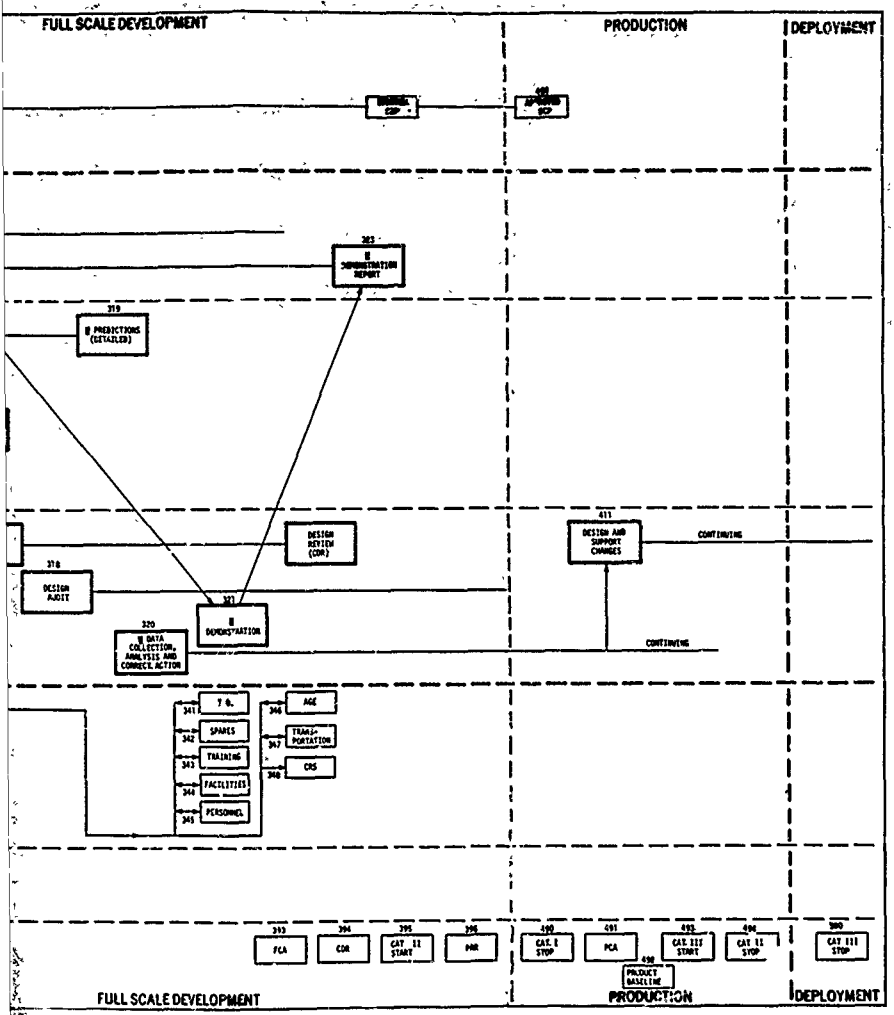
Conceptual	Validation	Full-Scale Development	Production	Deployment
Contractor or Procuring Agency	Contractor	Contractor	Contractor	Procuring Agency
Prepare M portion of support capabilities estimate (AI, Mct, Mpt, fault isolation, etc.)	Prepare proposal input in response to RFP	Conduct M program	Data collection, analysis, and corrective action	Data collection analysis and corrective action
Perform M trade-offs	Procuring Agency	Conduct design/ support trade-offs		Conduct test test.
Establish gross M requirements (qualitative and quantitative)	Evaluate proposal	Perform M and maintenance analysis effort		Update predictions, plans, etc.
Prepare preliminary maintenance concept (constraints)	Predictions and allocations	Conduct M test and demonstration		
Develop maintenance plan requirements	Trade studies	Data collection, analysis, and corrective action		
Prepare inputs to Request for Proposal	Support concept(s)			
	Design criteria and guidelines	Procuring Agency		
	Maintenance concept	Monitor contractor's M program		
	M program plan	Witness test		
	Demonstration plan	Participate in design reviews		
	Monitor contractor's efforts during validation (detailed preliminary planning and trade-off efforts)			


SUB-NOTE 1 (1) Maintainability Roadmap
CONCEPTUAL
100
RDC
101
PHD
102
OPERATIONAL CONSTRAINTS AND CONCEPT
103
DEPLOYMENT CONCEPT
RELATED PROGRAM FUNCTIONS
104
DCP
105
FUNCTIONAL BASELINE (SYSTEM SPECIFICATION)
200
PHP
201
APPROVED DCP
DOCUMENTATION
211
PROGRAM PLAN
REPORTS
214
106
ANALYZE M AND MAINTENANCE REQUIREMENTS AND ESTABLISH CONSTRAINTS
108
PREPARATION OF SPECIFICATION INPUTS
ANALYSIS
212
ALLOCATIONS
TRADE-OFFS (M RELATED)
215
MAINTAINABILITY (M) TASKS
213
CONCEPT REVIEW
OTHER M
270
TYPE
COMPLEXITY
ACCURACY
ENVIRONMENT
RELIABILITY
RELATED SYSTEM DESIGN TASKS
M RELATED MILESTONES
190
FUNCTIONAL BASELINE
290
CAT I START
CONCEPTUAL

A


VALIDATION
FULL SCALE DEVELOPMENT
303 UPDATED DCP
301 APPROVED DCP
UPDATED M PROGRAM PLAN
CONTINUOUS
M DEMONSTRATION PLAN
M DEMONSTRATION REPORT
315 M PREDICTION (EARLY)
319 M PREDICTIONS (DETAILED)
UPDATED TRADEOFFS
312
SPECIAL M ANALYSIS
316
M MODEL
217
313 SPECIAL M STUDIES
316 UPDATED M MODEL
317 DESIGN REVIEW (PDR)
DESIGN REVIEW (CDR)
318 DESIGN AUDIT
219 MAINT. CONCEPT
221 GFE INTEGRATION
222 M (DT&E) CRITERIA & SPEC INPUTS
321 M DEMONSTRATION
320 M DATA COLLECTION, ANALYSIS AND CORRECT. ACTION
340 MAINT. ANALYSIS
341 T.O.
342 SPARES
343 TRAINING
344 FACILITIES
345 PERSONNEL
346 AGE
347 TRANS-PORTATION
348 CRS
370
• TYPE
• COMPLEXITY
• ACCURACY
• ENVIRONMENT
• RELIABILITY
291 ALLOCATED BASELINE
292 CAT II TEST PLAN
390 PDR
393 FCA
394 CDR
VALIDATION
FULL SCALE DEVELOPMENT

B


FULL SCALE DEVELOPMENT
PRODUCTION
DEPLOYMENT
[redacted] CDP
[redacted] DCP
303
M DEMONSTRATION REPORT
319
M PREDICTIONS (DETAILED)
DESIGN REVIEW (CDR)
411
DESIGN AND SUPPORT CHANGES
CONTINUING
318
DESIGN AUDIT
321
M DEMONSTRATION
320
M DATA COLLECTION, ANALYSIS AND CORRECT ACTION
CONTINUING
341
T &
342
SPARES
343
TRAINING
344
FACILITIES
345
PERSONNEL
346
AGE
347
TRANS-PORTATION
348
CRS
393
PCA
394
CDR
395
CAT II START
396
PMR
490
CAT I STOP
491
PCA
498
PRODUCT BASELINE
492
CAT III START
494
CAT II STOP
380
CAT III STOP
FULL SCALE DEVELOPMENT
PRODUCTION
DEPLOYMENT

2.3 Maintainability Related Support Functions

These are the functions that maintainability impacts and guides to develop the logistic resources.

2.4 Maintainability Related System Design Data

These are the system engineering design functions that feed data (design, type, complexity, accuracy, environment, reliability) to maintainability and receive data from maintainability.

2.5 Maintainability Related Milestones

These are the major milestones of a system acquisition which maintainability keys on.

DESIGN NOTE 1B3 MAINTAINABILITY RELATED PROGRAM FUNCTIONS

1. REQUIRED OPERATIONAL CAPABILITY (ROC) (See DN 1B2, SN 1(1), block 100.)

The Conceptual Phase may begin with the statement of the operational deficiency or need. This statement may be expressed by Headquarters USAF or by a major command (MAJCOM) as a ROC (AFR 57-1).

Coordination with the using command should be emphasized. The process should begin with the submission of the ROC and continue throughout the acquisition. A more efficient system management will result when user requirements are known at all times. As problems arise, realistic trade-offs can be properly evaluated. This will provide a system optimized to user requirements. In addition, the user will be made aware of the management and technical problems as they occur and will be better prepared to support required program changes.

If such coordination is not maintained, there is the hazard of becoming so involved with the acquisition that the objective of providing the using command with a required capability may be threatened.

2. PROGRAM MANAGEMENT DIRECTIVE (PMD) ISSUED (See DN 1B2, SN 1(1), block 101.)

Headquarters USAF directs and guides appropriate action in the Conceptual Phase by means of a PMD. The PMD specifies the progress and acceptance of the program at Headquarters USAF and Office of Secretary of Defense (OSD) levels, including the actions to be performed by the commands to translate the ROC into a proposal for a new program.

3. OPERATIONAL CONSTRAINTS AND CONCEPT (See DN 1B2, SN 1(1), block 102.)

- Operating hours per unit calendar time
- Downtime or availability constraints
- Mobility requirements
- Self-sufficiency constraints
- Reaction time requirements
- Operational environment

4. DEPLOYMENT CONCEPT (See DN 1B2, SN 1(1), block 103.)

Typical outputs of interest:

- Number and locations of operational sites
- Number of operational systems per site
- Deployment schedule

5. ANALYZE MAINTAINABILITY AND MAINTENANCE REQUIREMENTS AND ESTABLISH CONSTRAINTS (See DN 1B2, SN 1(1), block 104.)

The ROC, as amplified in operational and deployment concept documents, represents the most fundamental statement of user need. A proper understanding and assessment of this need is critical to all subsequent program events, including those related to maintainability and maintenance planning.

During the Conceptual Phase, basic maintainability and maintenance constraints are derived through analysis of the stated user need for inclusion in appropriate sections of the functional baseline description. These constraints are typically both qualitative and quantitative in nature, addressing such subjects as maintenance philosophy, allowable downtime, and skill level limitations.

Formulation of maintainability and maintenance-related constraints is not necessarily a simple matter, since the user traditionally tends toward describing his requirements in terms of the job to be accomplished rather than in precise engineering language.

For example, assume that the ROC states, "Maintenance to be performed by the user." To the maintainability engineer charged with translation of this need into specification requirements, such a statement provides the basis for further analysis. Questions such as the following become pertinent:

Who is the user?

What maintenance AFSC's and skills does he currently possess?

In what environment does he normally operate and perform maintenance?

Answers to questions such as these lend considerable insight into the overall maintenance picture, and establish one segment of the foundation upon which specification constraints can be knowledgeably and rationally based. As the first rule of thumb, the maintainability analyst must strive to obtain compatibility between the using support structure and the developmental constraints which he derives.

Secondly, maintainability and maintenance-related constraints must be fully compatible with the operational mission for which the system or item is being developed.

That a keen awareness and understanding of this mission is essential to the maintainability analyst cannot be overly stressed.

Again, a simple statement of need should prompt a number of questions by the maintainability analyst. Assume the stated ROC need is to provide highly reliable communications as part of the XYZ intercontinental communications system.

This statement suggests questions such as:

How "reliable" is the XYZ system?

How does the equipment fit into this system, and how available must it be to be compatible with the overall XYZ system performance constraints?

What maintenance policies and procedures pertaining to the XYZ system must be considered as totally or partially applicable to the equipment?

For purposes of illustration, assume a ROC for a multiplexer set similar to that described in DN 1C1. Further assume that a thorough review of the needs set forth in this ROC has been completed, and the analysis prompted by this review has established the following:

- The Multiplexer Set will be deployed worldwide.
- Using organizations are technical control centers operating at fixed and semimobile (trailer van) installations. Each installation

will have five or fewer multiplexers. Some installations (10 percent or less) operate unattended. Communication links processed by unattended installations are noncritical.

- The XYZ system requires a critical communications link availability of 0.99.
- Each XYZ link is allocated an hour each month for downtime, enabling preventive maintenance. This downtime is excluded from link availability requirements.
- Using units have appropriate AFSC's in their maintenance organizations, but the vast majority of skills are at the -3 level.
- Installations processing critical communications links are constantly attended, and have "running spares" sets and maintenance personnel immediately available.

Based upon the above-listed information, we can begin the formulation of maintainability and maintenance-related constraints for inclusion in the functional multiplexer baseline.

5.1 Quantitative Constraints

Given that a critical XYZ communications link must be 0.9900 available, and the multiplexer is but one portion of an overall link, further investigation reveals a total link as depicted by SN 5.1(1). To existing nonmultiplexer elements of this link are assigned availability constraints obtained from individual element specifications.

From the figure, we see that the nonmultiplexer link elements represent an availability of 0.9901. Therefore, the multiplexer availability (x) must be:

$$(0.9901)\,(x) = 0.99$$

$$x = 0.9999$$

if the overall link availability of 0.99 is to be attained.

Next, conferring with persons familiar with designs similar to that envisioned

SUB-NOTE 5.1(1) XYZ Critical Communications Link
A = 0.99
A = 0.9901
Input Data
1/2 MUX
Send Buffer
Transmitter
Receiver
Receive Buffer
1/2 MUX
Output Data

for the multiplexer, it is determined that a complexity of approximately 4000 active electronic devices should be expected. The reliability (R) analyst, using this complexity estimate and empirical failure rate data, determines that a multiplexer MTBF of 2200 hours is reasonable and attainable. He will specify this value as part of his constraints.

We are now given a multiplexer availability requirement of 0.9999, and an MTBF requirement of 2200 hours. Using the expression

$$A = \frac{MTBF}{MTBF + \bar{M}_{ct}}$$

we can determine that the $\bar{M}_{ct}$ required of the multiplexer is:

$$0.9999 = \frac{2200}{2200 + x}$$

$$x = 0.2 \text{ hour}$$

The basic mean maintenance time constraint then becomes 0.2 hour, or 12.0 minutes.

As a rule of thumb, we know that a ratio of 1:3 exists between the mean and maximum (95th percentile) of typical maintenance task time distributions. Therefore, the maximum downtime ($M_{max\ ct}$ at 95th percentile) for the multiplexer is (3) (12.0) = 36.0 minutes.

We have also been given that the XYZ system tolerates 1 hour per month for preventive maintenance downtime. The multiplexer need simply be compatible with this environment.

Summarizing then, we can state that quantitative maintainability constraints applicable to the multiplexer are:

- Mean corrective maintenance time ($\bar{M}_{ct}$) shall not exceed 12.0 minutes.
- Maximum corrective maintenance time ($M_{max\ ct}$) shall not exceed 36.0 minutes (95th percentile).
- Preventive maintenance downtime shall not be required more frequently than once each 30 days, and shall not exceed 1 hour in duration.

5.2 Qualitative Constraints

Certain qualitative maintainability and maintenance-related constraints are applicable to essentially all developmental programs, and ours is no exception.

Establishment of qualitative constraints requires that the analyst take a comprehensive overview of the maintenance and support situation. Skill levels, time constraints, and other factors must be considered in combination, as well as singularly. Other nonmaintainability constraints must also be examined for their influence.

In the above illustration, we established an $\overline{M}_{ct}$ constraint of 12.0 minutes. Such a low value, combined with the expected multiplexer complexity, suggests that some form of assistance should be provided for localizing and/or diagnosing detected faults. Further, by virtue of the skill levels available in the anticipated using units, maintenance must be as simple and straightforward as possible. It follows, then, that repairs be accomplished by exchange of subassemblies or modular entities rather than by exchange at the discrete part level.

Another factor bearing upon fault isolation considerations is the reliability constraint. Although the multiplexer will operate continuously, the 2200-hour MTBF constraint yields an average of only four failures per year. Such a low corrective maintenance frequency, with the attendant difficulties in maintaining maintenance proficiency, further dictates that the overall maintenance task be as simple as possible. Extensive procedural fault localization and isolation routines must be avoided.

Although we are satisfied that some form of diagnostics aids will be required, it should be recognized that any such aids have inherent limitations. For this reason, correction of certain failures will entail conventional troubleshooting processes. We should therefore also plan to assist these processes by establishing a requirement or constraint addressing test points.

Based upon the above discussion, it should be seen that certain qualitative constraints are rational, logical, and necessary. For the multiplexer illustration, they may be summarized as follows:

- Provide integral diagnostic aids enabling corrective maintenance at the subassembly level within the specified maintenance time constraints.
- Required maintenance tasks shall be within the capabilities of appropriately trained personnel of -3 skill levels.
- To the greatest extent possible, requirements for charts, tabular listings, and technical publications in support of malfunction isolation tasks shall be avoided.
- Readily accessible test points shall be provided within the multiplexer for purposes of assisting in the isolation of faults not treated by integral diagnostic aids.

In the preceding discussions of quantitative and qualitative maintainability and maintenance-related constraints, we should see that the necessity for such constraints can be established in a logical manner, based upon a comprehensive assessment of the stated user need. It should be firmly recognized that the thoroughness and validity of this constraint derivation in the Conceptual Phase is of vital importance, since all subsequent development activities are based upon these constraints. The objective should always be one of properly expressing the user's need. Understatement will result in failure to obtain expected performance, and overstatement will result in added cost and complexity.

6. PREPARATION OF SPECIFICATION INPUTS (See DN 1B2, SN 1(1), block 105.)

Maintainability and maintenance-related constraints derived from analysis of the stated user need must be included in the Functional Baseline description. This description takes the form of a System Specification, to which subsequent development efforts are addressed.

The System Specification is prepared in a prescribed format, as established by governing configuration data management procedures.

In the introductory portions of the specification, a brief summary of the overall operational and support mission is included. Such a summary should provide the contractor(s) with a general understanding of both the intended utilization for the item being developed, and the environment in which this utilization will be accomplished. A discussion of basic maintenance philosophy should be included, together with appropriate notations of those support-related requirements which are of particular importance. Because developmental specifications leave a considerable degree of latitude as to the actual configuration the item will assume, making the contractor aware of any particularly desirable characteristics will allow him to orient his design to their satisfaction.

Another portion of the specification is reserved for expressing specific performance constraints, and relates item form, fit, and function requirements in precise engineering detail. It is in the segment of the specification that the maintainability and maintenance-related constraints derived from the user's need statement are expressed. These constraints are typically of both qualitative and quantitative kinds.

Finally, the System Specification provides a section addressing the methods and criteria by which the degree of satisfaction of specified performance requirements can be assessed. In the case of maintainability, a formalized demonstration is typically required.

In summary, the preparation of specification inputs provides the vehicle by which support-related information and constraints are documented in preparation for subsequent validation and development activities.

7. SECRETARY OF DEFENSE (SECDEF) APPROVES DEVELOPMENT CONCEPT PAPER (DCP) (See DN 1B2, SN 1(1), blocks 106 and 202.)

The SECDEF approves and signs the DCP and provides comments and guidance for the next phase. The signed DCP completes the program decision, and the program is funded and directed to proceed to the Validation Phase.

8. FUNCTIONAL BASELINE (See DN 1B2, SN 1(1), block 107.)

The functional baseline (program requirements baseline) is established by the end of the Conceptual Phase. It includes broad system performance objectives, an operational concept, a logistics and maintenance concept, and cost estimates. The system specification defines the technical portion of the program requirements baseline. The Air Force and the OSD use this information to evaluate the proposed program and to compare it with competing programs. After review and approval, this baseline is the basis for the Validation Phase.

9. PROGRAM MANAGEMENT PLAN (PMP) (See DN 1B2, SN 1(1), block 202.)

If not directed to be submitted at an earlier point in time, the PM prepares, approves, and issues the PMP as soon as possible after program approval to proceed with development. The PMP should be in consonance with program direction (PMD, AFSC Form 56, and any AFSC intermediate command supplementary direction). Even though the PM is responsible for the overall preparation and issuance, the PMP usually requires considerable cooperation and coordination efforts with other major commands such as the Air Force Logistics Command, Air Training Command, and the operating command. The coordination should be completed prior to approval of the PMP. The PMP is the singular program management baseline document and will be used by participating agencies and higher level decision authorities. Hence, it must be kept current to reflect the approved program and plans for any follow-on unapproved phases. (See AFR 800-2/AFSC Sup 1 for basic PMP requirements, and attachments 4 and 5 for guidance/information regarding preparation of PMP's.)

10. APPROVED DCP (See DN 1B2, SN 1(1), block 203.)

Approval of the DCP constitutes the ratification decision. This decision depends upon confirmation of the technical, financial, and schedule constraints. As a result of the Validation Phase, the Air Force will make recommendations regarding further program development activity.

11. ALLOCATED BASELINE (See DN 1B2, SN 1(1), block 291.)

The allocated baseline (design requirements baseline) is established during the Validation Phase. It incorporates the technological approaches developed by contractors to satisfy the objectives in the functional baseline (program requirements baseline). During the Validation Phase, these objectives are translated into system segment, subsystem, and configuration item (CI) performance requirements and design constraints. Cost targets and schedules for carrying out each part of the program are included. The allocated baseline is the basis for detailed design and development of the system by the contractor during the Full-Scale Development Phase (AFSCP 375-1).

12. APPROVED DCP (See DN 1B2, SN 1(1), block 301.)

The approval of the DCP constitutes the production decision. This decision, made by the SECDEF after consultation with the Defense System Acquisition Review Council (DSARC), determines whether to produce the system for operational use, defines the initial quantity to be produced, and approves plans for future production. Sufficient testing should have demonstrated that engineering design for performance is completed. In addition, production engineering must be essentially completed and production capability confirmed to the extent practical. The engineering design should be analyzed by production engineers to ensure production compatibility and capability.

13. PHYSICAL CONFIGURATION AUDIT (PCA) (See DN 1B2, SN 1(1), block 491.)

The PCA is a formal audit which compares Part II Detail (Product Fabrication) Specifications and accompanying drawings with the hardware produced. The product of the PCA is formal PM acceptance of the Part II Detail (Product Fabrication) Specifications as audited and approved documents which satisfy a contractual obligation. PCA is a prerequisite to configuration item acceptance.

14. PROGRAM DOCUMENTATION UPDATED (See DN 1B2, SN 1(1), block 492.)

The product baseline should be as complete as possible for the production contract RFP, even though updating will continue until the PCA. The Part II Detail (Product Fabrication) Specifications and reference drawings for hardware and real property facilities should be nearing completion. These specifications represent the product of preliminary design, detail design, Category I testing, and verification reviews. The product configuration baseline represents the integrated design solution generated by the acquisition process. Part II Detail (Product Fabrication) Specifications can be used for fabrication, production, construction, PCA, and hardware acceptance and reprocurement.

15. PRODUCT BASELINE (See DN 1B2, SN 1(1), block 492.)

Successful completion of the PCA establishes an approved product configuration baseline for the CI and marks the beginning of formal engineering change control for Class I design changes.

16. CATEGORY I TEST START (See DN 1B2, SN 1(1), block 290.)

Recent AFSC studies have espoused stronger Air Force control and participation in Category I testing. Test center responsibilities during these tests include assumption of early planning for new programs with active participation in development of test plans. The responsible test organization (RTO) should be involved in the contractor's test activities to observe test procedures, review results, and assure continuity.

The hardware to be tested is normally produced by other than production methods and probably in a prototype form. The testing performed at this point should be accomplished to check the design to see that it is functional. Complete qualification testing is not normally done at this time.

Subsystem development, test, and evaluation begin in the Validation Phase. The testing aids in redesign, refinement, and reevaluation. The Air Force actively participates in, evaluates, and controls Category I testing; however, the test is conducted predominantly by the contractor, who is under the PO's direction and control (AFR 80-14). The Category II test plan will be initiated during this phase.

17. CATEGORY II TEST PLAN AND START (See DN 1B2, SN 1(1), blocks 292 and 395.)

The Category II test plan was initially prepared by the AFSC test center and the PM during the Validation Phase. The Air Force should revise and expand the plan based on the latest information and prepare procedures that the Air Force, with contractor participation, can use in conducting Category II tests. Procedures should implement Section 4 of the System Specification and the Part I Detail Specifications. Emphasis should be placed on integrated evaluation of all system segments required to accomplish the mission. Individual system end items or CI's critical to overall system performance should be monitored to assure that outstanding technical problems noted during earlier tests and evaluations have been resolved. The Air Force should control this testing and evaluate the results. Contractor prepared test plans, data, and test results should be reviewed and approved by AFSC test agencies and the PM. Procedural changes should be approved by the Air Force representative on the scene. Emphasis should be placed on integrated evaluation of all systems required to accomplish the mission in the projected environment which the system will be subject to during operations. All system end items or CI

testing should be monitored to assure that requirements are being met and that outstanding technical problems noted during earlier tests and evaluations have been satisfactorily resolved.

18. CATEGORY I AND CATEGORY II TEST (See DN 1B2, SN 1(1), blocks 490 and 494.)

Tests as described in the Full-Scale Development Phase are continued during the Production Phase. System elements are integrated into a complete system in as near an operational configuration as possible. Category II testing is not complete until system performance requirements are met. A qualification statement as required by AFSCR/AFLCR 80-16 will be written at the end of the tests.

Procedural publications (preliminary manuals) may be used and simultaneously verified in Category II tests.

19. CATEGORY III TEST (See DN 1B2, SN 1(1), blocks 493 and 590.)

The using command conducts Category III tests with the approved plans and procedures. Operational testing and evaluation (OT&E) of the production items should be conducted on the early production models to detect and correct unacceptable deficiencies at the earliest opportunity. These tests are conducted under actual or simulated operational conditions.

The using command establishes requirements for Category III testing and prepares the plans and procedures for implementing the requirements. Category III test requirements include an assessment of system operational capabilities, development of tactics and procedures, and evaluation of the logistic system training and procedural publications in an operational environment (AFR 80-14).

Although testing begins in the Production Phase, [illegible] ing must be initiated soon after the beginning of Category II testing in the Full-Scale Development Phase.

Category III testing uses a configuration jointly agreed upon by the using commands, AFSC, and AFLC. Testing may be conducted at the using command, AFSC, or some other designated installation. Engineering support will be provided by AFSC and AFLC.

DESIGN NOTE 1B4 MAINTAINABILITY TASK DESCRIPTION

1. MAINTAINABILITY PROGRAM PLAN (See DN 1B2, SN 1 (1), block 211.)

In the proposal, a contractor should describe how he plans to develop and conduct the maintainability program to meet the requirements of the RFP and the tasks identified in Chapters 3 through 17 of this notebook. The amount of detail submitted may vary depending on the program phase. These portions of the Maintainability Program Plan, specifically identified and mutually agreed upon by the contractor and the procuring activity, should become part of the contract. A detailed description and example of these program plans are included in Chapter 3.

2. MAINTAINABILITY ALLOCATIONS (See DN 1B2, SN 1 (1), block 212.)

The quantitative mean corrective time for the system is allocated down to the subsystem, assembly, or subassembly level in compliance with the established maintenance concept. Allocated maintainability is based upon the predicted failure rates. A detailed description and example of maintainability of allocation are included in Chapter 5.

3. DESIGN REVIEWS (See DN 1B2, SN 1 (1), blocks 213, 317, and 322.)

Design reviews are conducted throughout the product design cycle, in accordance with contract requirements, as an integral part of the contractor's system engineering review and evaluation program. The reviews are conducted so that particular aspects of the work or the entire system can be reviewed by a Design Review Board, an objective group of program personnel, and specialists in the particular field. Maintainability is represented by a board member.

Some major design review monitoring points are detailed below.

3.1 Design Concept Review (See DN 1B2, SN 1 (1), block 273.)

There should be an overall system concept to ascertain that the elements of the system are assigned the necessary and proper functions which will satisfy the required characteristics. Further, there should be a concept review of each system element to ascertain that its design will perform the assigned functions in the best possible manner.

3.2 Preliminary Design Review (See DN 1B2, SN 1 (1), block 317.)

At this point, the initial system design is nearly complete and many component parts and assemblies will have undergone some development testing. Some of the factors to be considered at this review are adherence to specifications, reliability, maintainability, safety of personnel, appearance and human engineering factors, economy of manufacture, environmental adequacy, and compatibility.

3.3 Critical Design Review (See DN 1B2, SN 1 (1), block 322.)

At this point, the production design of the system is essentially complete and the system is considered ready for production. This review should place special emphasis on attainment of minimum life cycle cost for the system. A detailed description and example of design reviews are included in Chapter 4.

4. MAINTAINABILITY REPORTS (See DN 1B2, SN 1 (1), block 234.)

For proper monitoring of the contractor's maintainability program effort, maintainability status reports are required at intervals determined by the procuring activity. The same type of status information required by the procuring activity is needed also by the contractor for successful maintainability program management. These reports may be combined with other system program status documentation, provided all maintainability information is

summarized in a separate section and all supporting information is cross-referenced. The status report should provide a current accounting of required, allocated, predicted, and observed maintainability values for the system or equipment and its constituent elements. Further, it should give a narrative and graphical treatment of trends, problems encountered or anticipated, and action taken or proposed. The status report will be a key source of official information and communication between the contractor's maintainability group and the procuring activity's maintainability monitor, and should be treated in that light. A detailed description and examples are included in Chapter 6.

5. TRADE-OFFS (See DN 1B2, SN 1 (1), blocks 215 and 312.)

During the system development, in order to achieve optimum operational capability at the minimum life cycle cost, it is necessary to make design and support concept trade-offs. The maintainability organization should be an integral part of the design trade-off decision and should, whenever maintainability requirements or principles are compromised, document and justify the change or make recommendations for alternative design changes which do not compromise maintainability and maintenance support. A detailed description and example of design Trade-offs are included in Chapter 7.

6. SPECIAL MAINTAINABILITY ANALYSIS (See DN 1B2, SN 1 (1) blocks 216 and 313.)

Maintainability Analysis should be performed on all design concepts, drawings, and hardware items. The analysis is a continuing process that begins in the Validation Phase and continues throughout the program. The procedures for such an analysis vary with the complexity of the equipment, intended use, and the degree of design available. A design evaluation is performed on each concept, drawing, and engineering model to record the pertinent facts related to maintainability of the system. The analysis is used as a common basis for

evaluating the degree of achievement of the maintainability design goals, evaluating the logistic and personnel subsystem implications, and evaluating system candidates in relation to the operational requirements and maintenance constraints. This analysis is performed prior to conducting trade-offs related to program life cycle cost to verify that each candidate satisfies the operational requirements and maintenance/maintainability constraints. A detailed description and example of special maintainability analysis are included in Chapter 8.

7. MAINTAINABILITY MODELING (See DN 1B2, SN 1 (1), blocks 217 and 316.)

To implement and update the maintainability model, the system contractors should use a mathematical model as an aid to allocating and predicting maintainability parameters, making design and support concept trade-offs, and assessing the progress of the maintainability program. The complexity of the model will necessarily vary according to the complexity of the equipment being procured. For very simple items, the model may be structured so that all inputs, computations, and parameter changes are accomplished manually. Complex systems may require a totally computerized model. In any event, the model must allow data to be input at the lowest functional level at which the data is available and provide outputs at each higher indenture. Initially, maintainability estimates or allocations may only be possible at high equipment indentures. As designs become finalized and testing proceeds, lower indenture information will become available. The model must be readily adaptable to make use of the more detailed information. The requirements may be incorporated into a higher level system effectiveness or logistic support model or used to develop a separate maintainability model. In the latter instance,

or if no other mathematical model is required by this contract, the contractor should ensure that interfaces between his maintainability organization and other activities will include automatic exchange and use of all data which affects the development efforts of others.

To the contractor, the primary value of this model will be related to his progress in achieving specific contractual requirements. The customer will, in addition, be interested in the expected system or equipment maintenance required during actual operational use. Although contractual values should be based on operational requirements, the two may not be exactly equal because of such factors as cannibalization, administrative maintenance delays, maintenance charged to unconfirmed failures, or later changes in the intended operational environment. Therefore, the model should provide visibility of both the contractual obligations and the expected operational performance and must have flexibility to allow changes in the operational parameters. A detailed description and example of the maintainability modeling are included in Chapter 9.

8. MAINTENANCE CONCEPT (See DN 1B2, SN 1 (1), block 219.)

The maintenance concept is developed in conjunction with the design concept, both of which are based on the maintainability analysis of the mission and operational requirements and the maintainability and maintenance constraints established in the contract. The results of repetitive maintainability analysis will yield a system which demonstrates maximum avilability per dollar cost and which may reflect drastic changes in the preliminary concept or plan. A detailed description and example of the maintenance concept are included in Chapter 10.

9. GOVERNMENT FURNISHED EQUIPMENT INTEGRATION (See DN 1B2, SN 1 (1), block 221.)

When items other than system/equipment contractor's items are integrated into the system, such as government furnished equipment (GFE) or associate contractor supplied equipment, the contractor should request maintainability

parameter values from the procuring agency and should use these values in the maintainability analysis to arrive at the maintainability values to be entered in the contract specifications. If these maintainability values are unavailable or unknown, the contractor should estimate the maintainability parameter values.

In integrating this equipment into a new system, an [illegible]s should be performed to make the most cost effective decisions regarding its support. In this analysis, candidates such as providing maintenance in an already established facility or acquiring the resources to support it with the rest of the system should be considered.

10. MAINTAINABILITY DESIGN CRITERIA AND SPECIFICATION INPUTS (See DN 1B2, SN 1(1), block 222.)

The preliminary guidelines and criteria shall be periodically updated based upon results of maintainability analysis until such time as the detailed specifications are prepared.

The primary guideline for the maintainability engineer in the development of specification is as follows: If a qualitative or quantitative goal is required and if it can be tested or verified, then the goal must be stated in the specification. In the evolution of specifications from a goal, the wording must also reflect the definitive nature of the requirement. All effort must be extended to eliminate the use of such vague wording as minimize, maximize, etc. A detailed description and example of design criteria and specifications inputs are included in Chapter 12.

11. MAINTAINABILITY PREDICTIONS (See 1B2, SN 1 (1), blocks 315 and 319.)

The maintainability prediction is an estimate of the adequacy of the proposed design to meet the maintainability time requirements and a method to

identify design features requiring corrective action. Predictions are conducted throughout the early phases and continuously updated as design changes are made through maturity of the system. A detailed description and example for predictions are included in Chapter 13.

12. MAINTAINABILITY DESIGN AUDIT (See 1B2, SN 1 (1), block 318.)

Maintainability engineers assigned to the maintainability organization (contractor) establish and maintain daily contact with applicable groups (systems, design, reliability, packaging, etc.). This liaison ensures that all project functions are aware of and react to maintainability requirements. This continuous audit also ensures that maintainability is current on all technical and planning areas so that a compatible program is in effect. A detailed description of maintainability design audit is included in Chapter 14.

13. MAINTAINABILITY DEMONSTRATION (See DN 1B2, SN 1 (1) block 321.)

The maintainability effort that is conducted throughout the program should yield, with some high degree of confidence, compliance with the system specified quantitative and qualitative requirements. This assurance has been developed through the analyses, predictions, and reviews performed during the program. The formal demonstration of compliance with these requirements should be conducted by the contractor and monitored by the procuring agency. Failure to meet the requirements may result in corrective action (i.e., design changes), loss of incentive fees, or possible cessation of the program, depending on the severity of the impact on the system effectiveness. A detailed description and example of maintainability demonstration are included in Chapters 15 and 16.

14. MAINTAINABILITY DATA COLLECTION, ANALYSIS, AND CORRECTIVE ACTION (See DN 1B2, SN 1(1), block 320.)

Throughout the program, information and data pertinent to the maintainability and supportability parameters shall be collected and analyzed, and action initiated as applicable. Conflict of maintainability recommendations with other design parameters shall be arbitrated at design reviews for satisfactory compliance with system requirements.

The contractor shall establish a data collection system tailored to the specific requirements of the program contract for prediction during design and then documentation of demonstration results.

Further collection and assessment of reliable maintainability performance data are essential to the development of maintainability requirements for new systems. A data collection system should be capable of application throughout the life cycle of a new system and should be capable of accepting data from existing and/or proposed data systems in use by the government.

The maintainability organization (contractor) shall assure that problems affecting the maintainability of system/equipment shall have corrective action responsibility assigned and shall follow up for timely resolution of such problems. A detailed description and example of data collection and corrective action are included in Chapter 17.

DESIGN NOTE 1B5 COST OF MAINTAINABILITY TASKS

1. COST ESTIMATORS

The cost estimators developed in this section are intended for use in pricing the conduct of the maintainability program on a task-by-task basis, with the common denominator for the measurement of the conduct of maintainability tasks being man-hours. (For a detailed description of each task, refer to DN 1B4.) Since the systems considered are primarily ground electronics systems, the man-hours for each task are plotted against the quantity of printed circuit cards and/or modules contained therein (these being an indication of hardware complexity), with a mean IC density of 22. The exceptions to this are GFE integration, whereby the quantities of GFE items integrated are plotted against the man-hours required to do so, and demonstration conduct and demonstration reports, whereby the number of samples demonstrated is related to man-hours.

The relationships depicted by SN 1 (1) through SN 1 (16) result from data collected on 17 programs, which represent a cross-section of communications, computer, guidance, radar, tracking, and telemetry systems. The information depicted by each plot was derived by linear regression analysis, with the exception of GFE integration, SN 1 (9), which, because of limited sample size, is a plot of the arithmetic means of the dependent and independant variable. Of the points plotted, 68 percent fall within the limits depicted by ± 1 sigma (σ). The wide variation in some of these "street widths" can be accounted for by differences in customers and their requirements, the wide variety of the systems analyzed, differences in card complexities, and the wide differences in the lengths of the acquisition phases of the various programs. The plots are additionally useful in that, once having determined a program's relative position within the street, the slope of the curve is valid for any variation in system complexity, whether brought about by change in program philosophy, engineering growth, or revisions to maintenance philosophy.

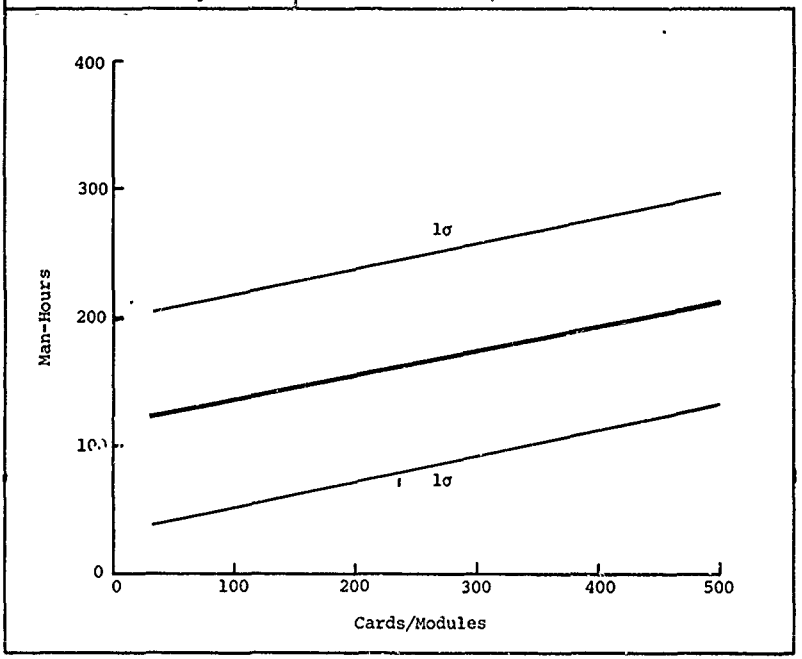
SN 1 (17) and SN 1 (18) are recapitulations of the man-hours required for conducting a complete maintainability program (with the exception of GFE

DESIGN NOTE 1B5 COST OF MAINTAINABILITY TASKS

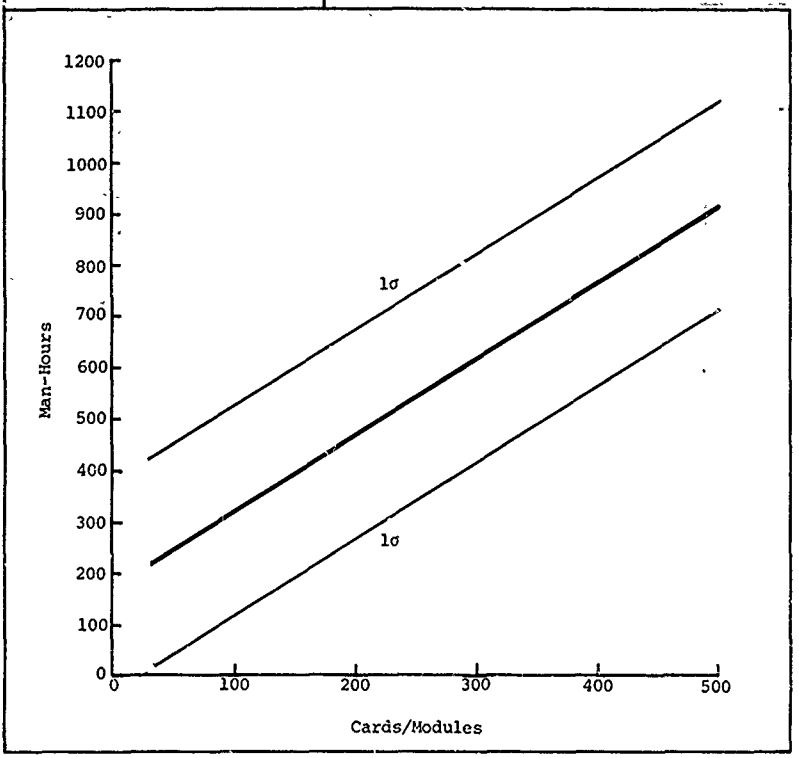
integration) in terms of cards/modules and samples, respectively, and are merely the arithmetic sums of the individual task coordinates. To arrive at the cost of a complete program which, for example, has a card density of 100, and a demonstration sample size of 30, the estimator merely needs to find the corresponding values of man-hours in SN 1 (17) and SN 1 (18) and add them. In the example stated, the man-hours required for performing all tasks but demonstration conduct and report are 3,629; and the man-hours required to conduct and report on a demonstration of 30 samples are 399. The total of 4,028 represents the man-hours required to perform all of the maintainability functions described in SN 1 (1) through SN 1 (8) and SN 1 (10) through SN 1 (16). If GFE items are to be integrated into the tactical system (SN 1 [9]), the man-hours required to effect this must also be considered.

Recognizing the fact that the accuracy of the curves is something less than 100 percent, due primarily to a limited, finite sample size of the data collected, the results, nevertheless, are usable to the extent that they serve as a point of departure in the early program phases. As more and increasingly accurate data becomes available, the curves can be further refined, and, if to the estimator's advantage, reformatted. Future updates of this document will incorporate any additional data provided to the RADC office. Any comments or data furnished in this regard will be appreciated.

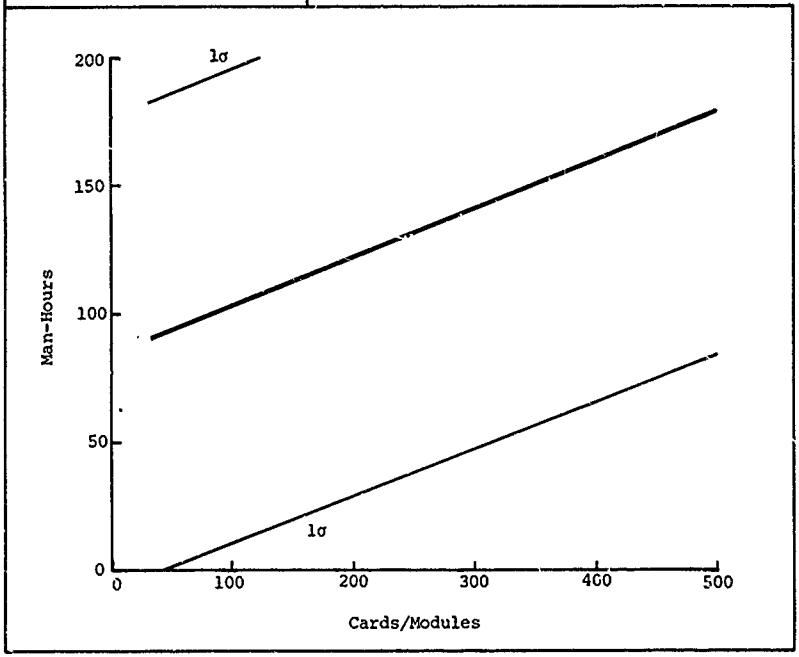
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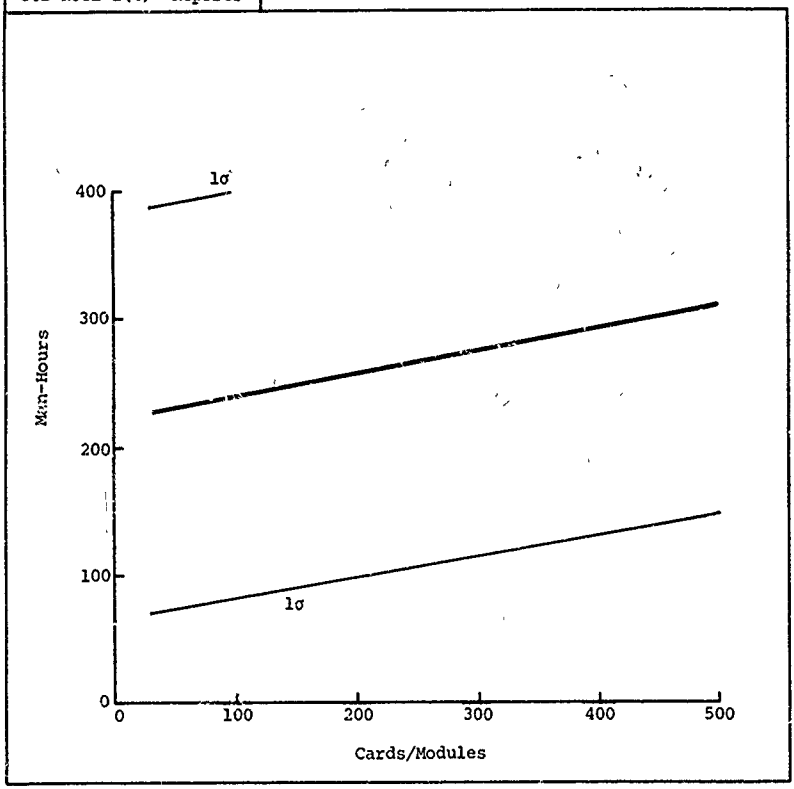
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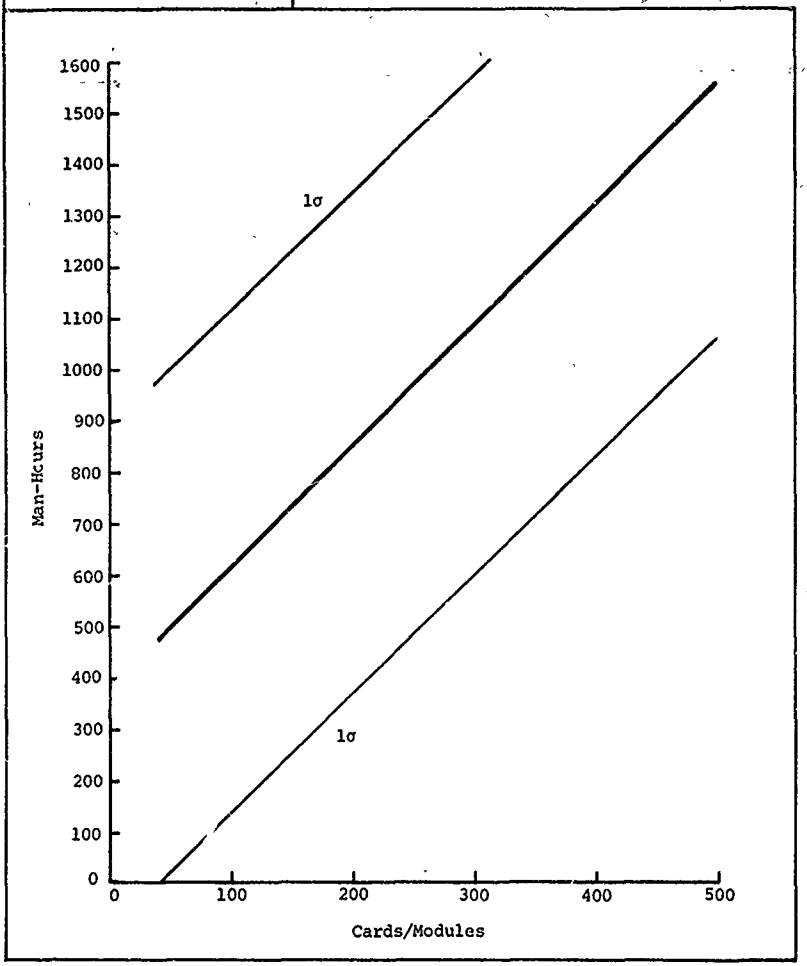
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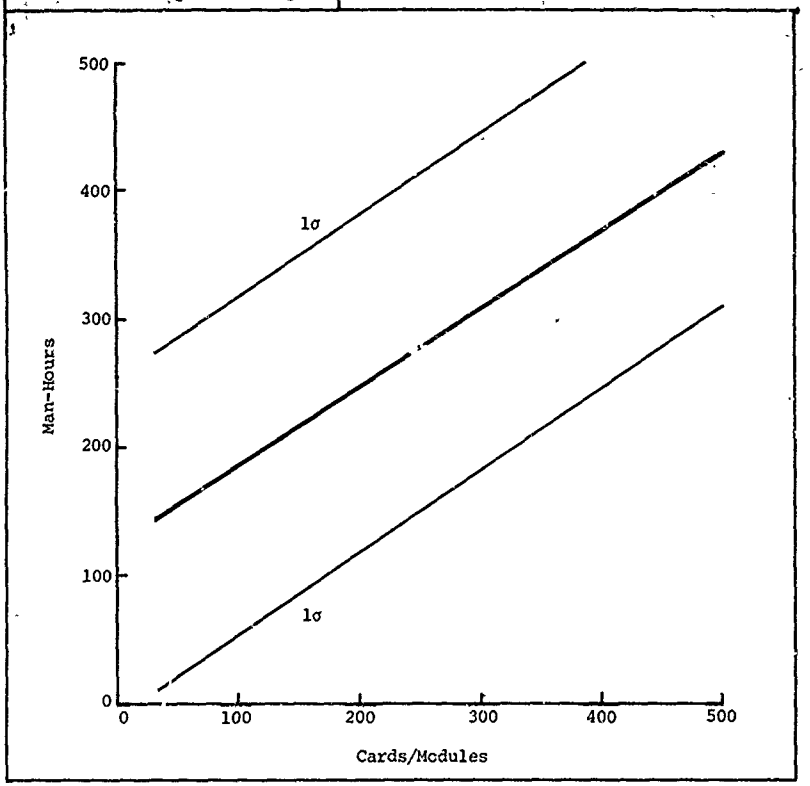
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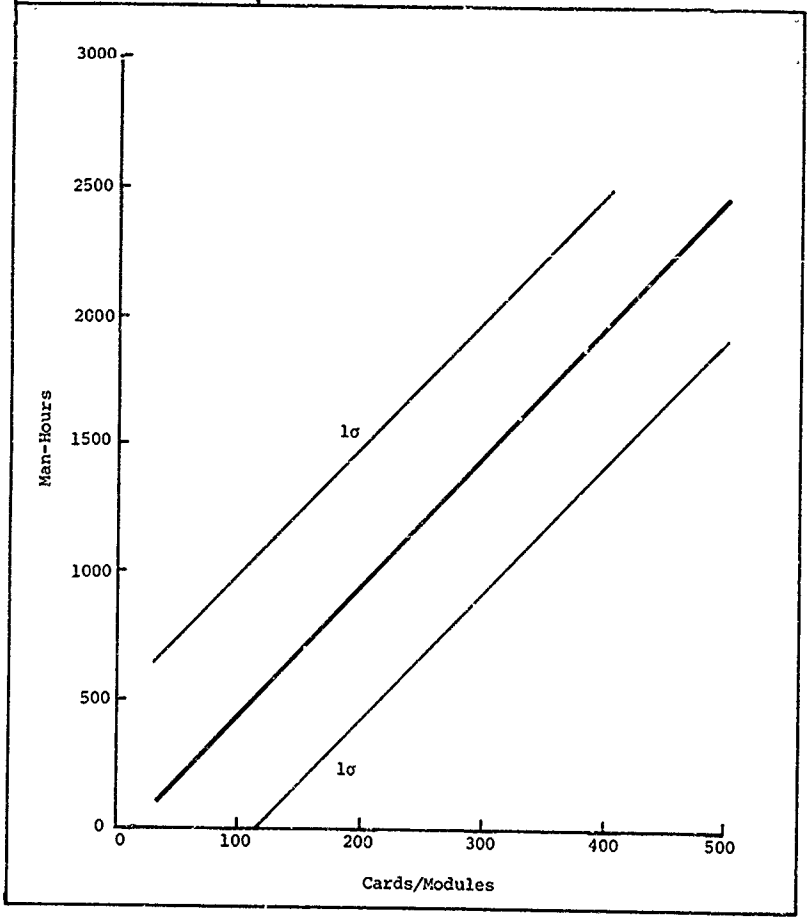
SUBSCRIPE 1(5) Trade-Offs



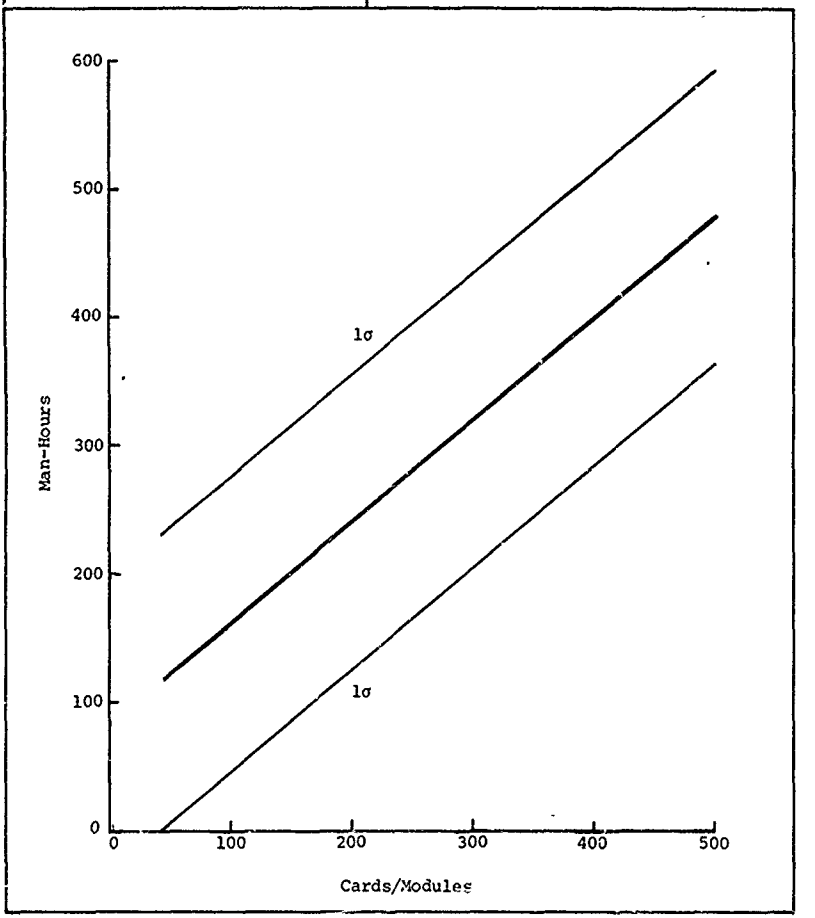
SUB-NOTE 1(6) Special Analysis



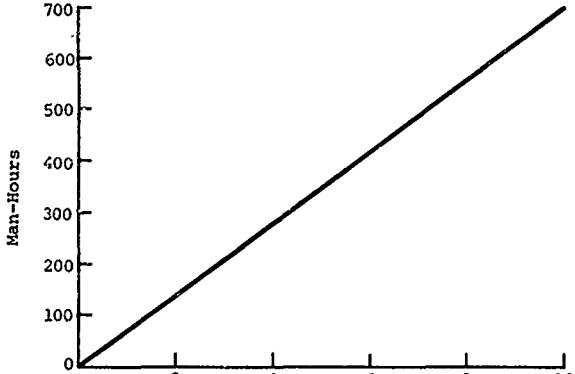
SUB-NOTE 1(7) Models



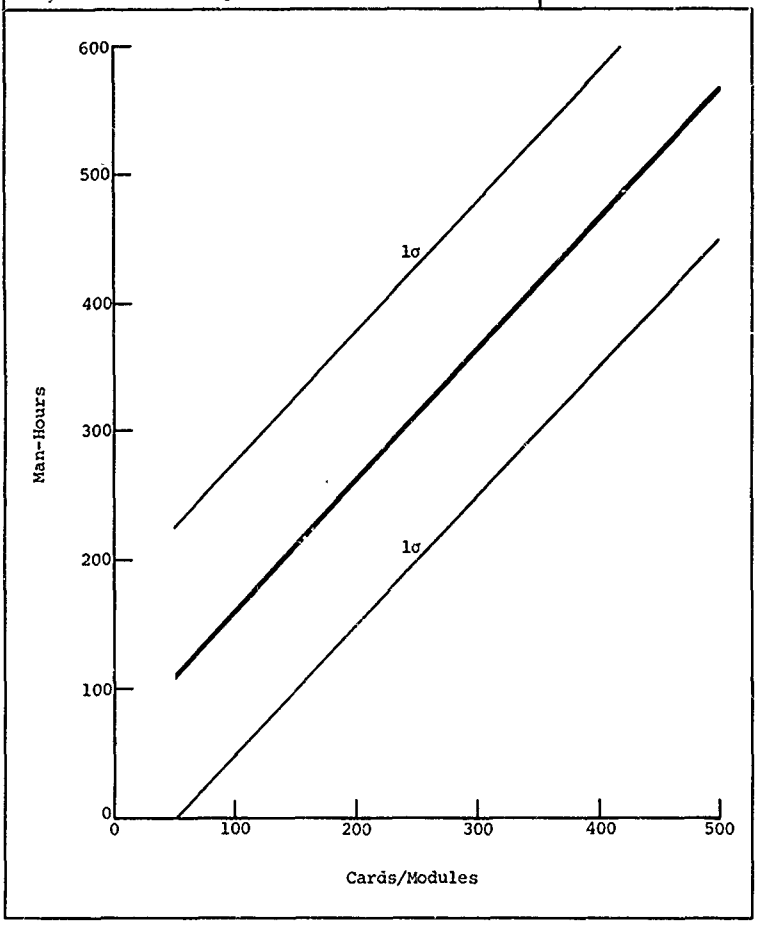
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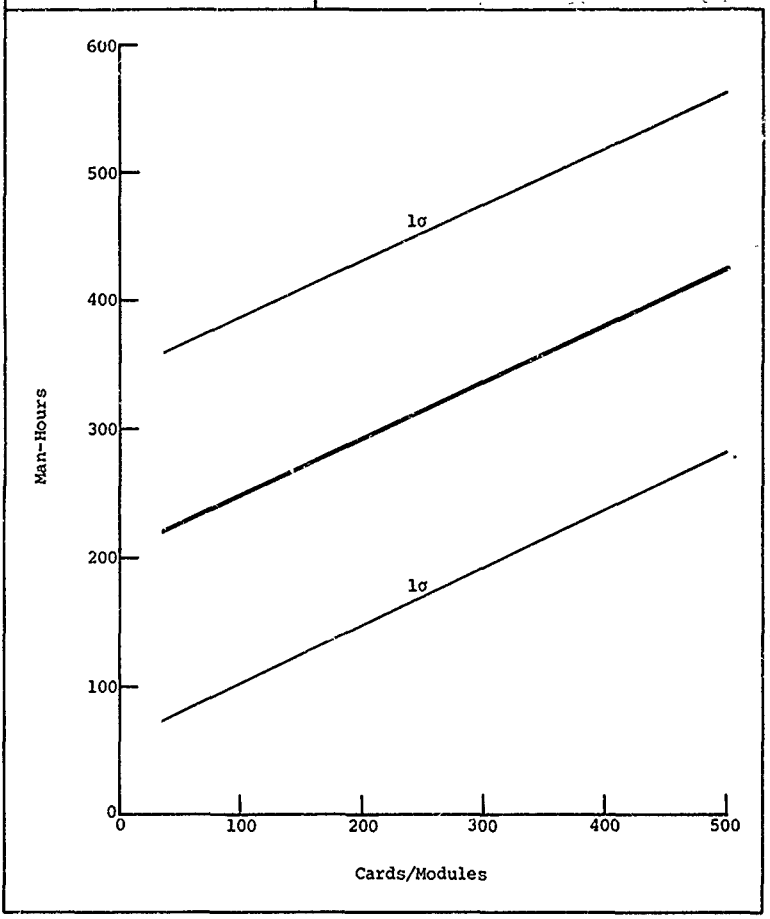
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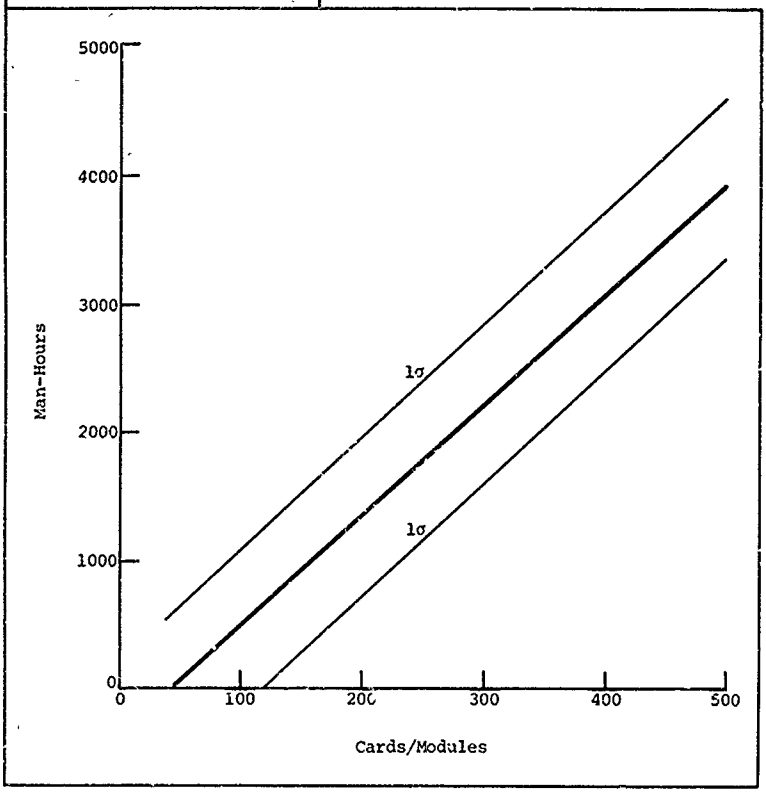
SUB-NOTE 1(10) Design Criteria and Specifications



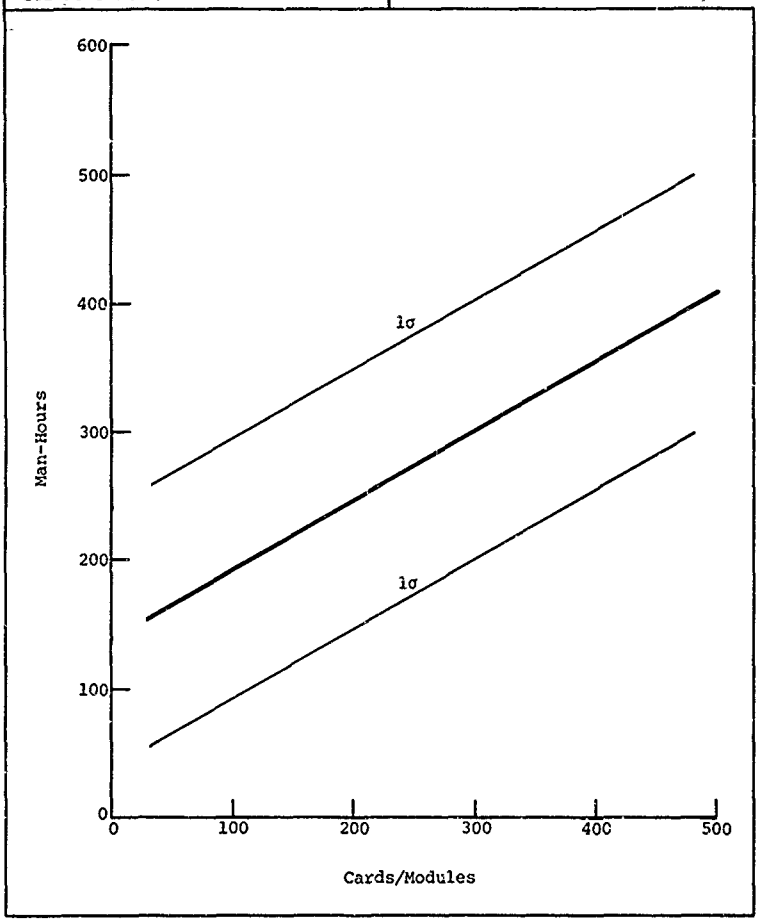
SUB-NOTE 1(11) Predictions



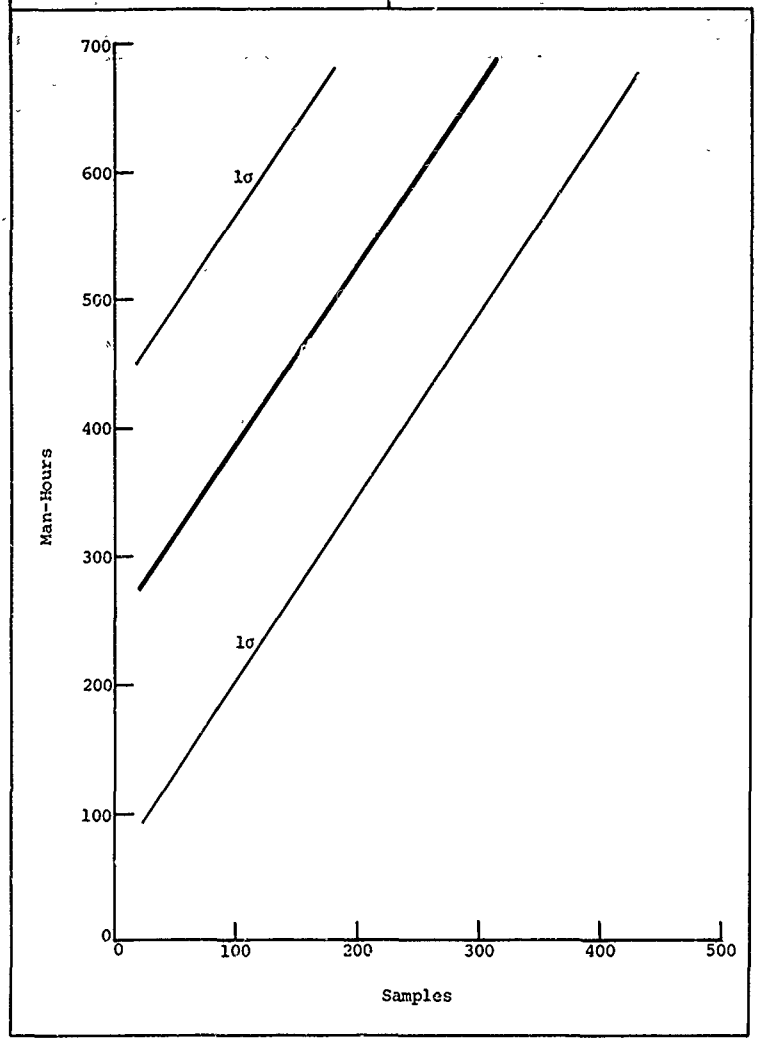
SUB-NOTE 1(12) Design Audit



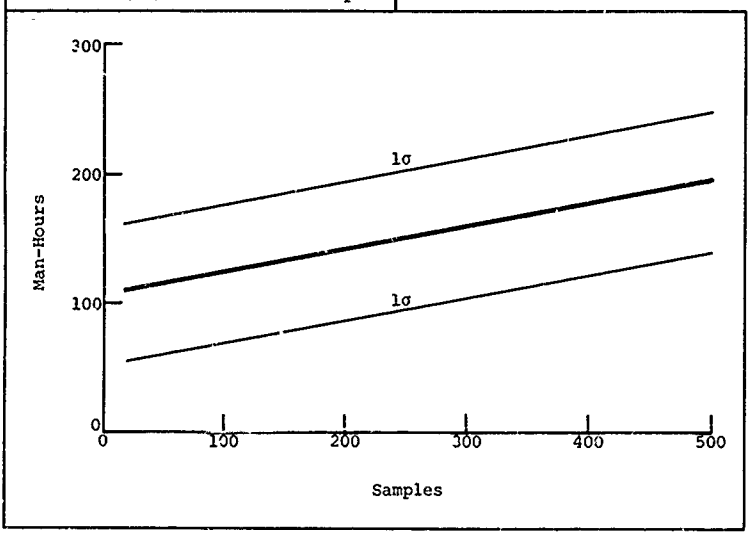
SUB-NOTE 1(13) Demonstration Plan



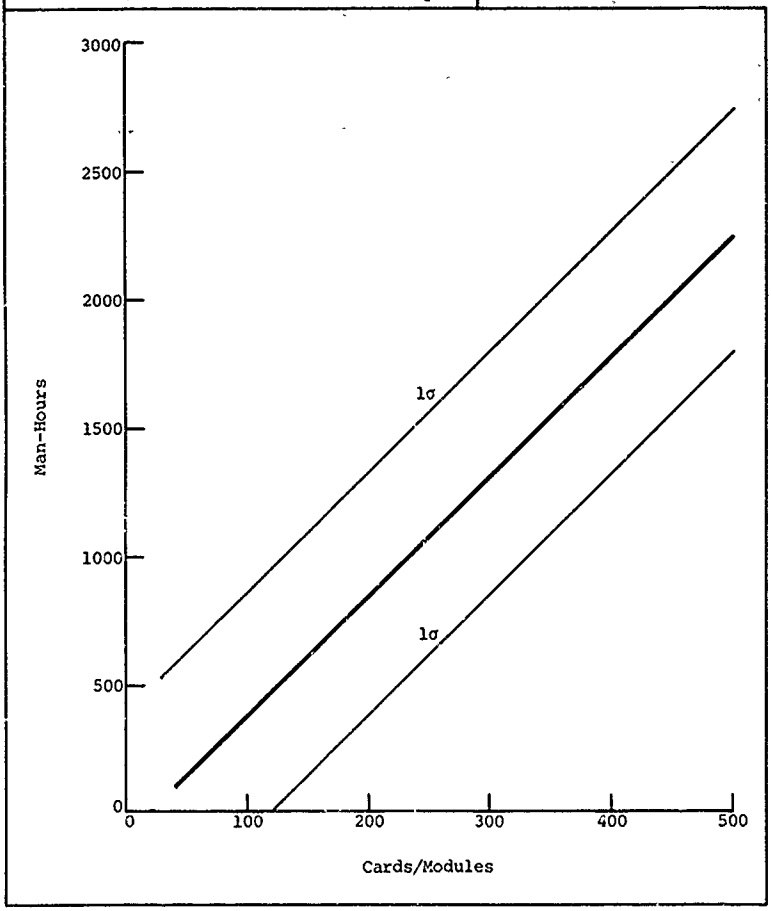
SUB-NOTE 1(14) Demonstration Conduct



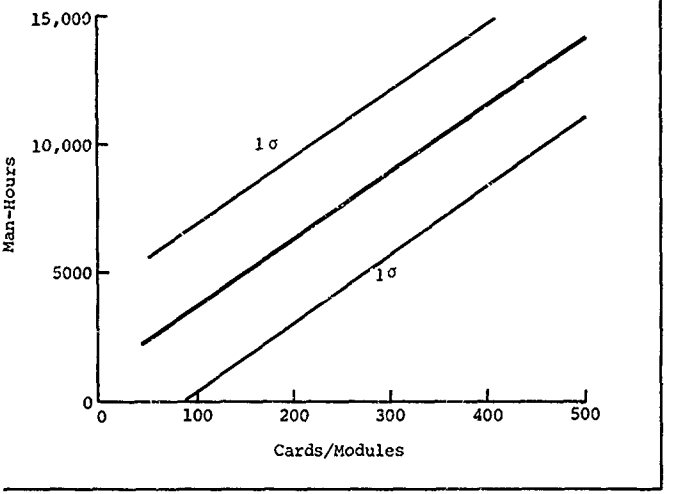
SUB-NOTE 1(15) Demonstration Report



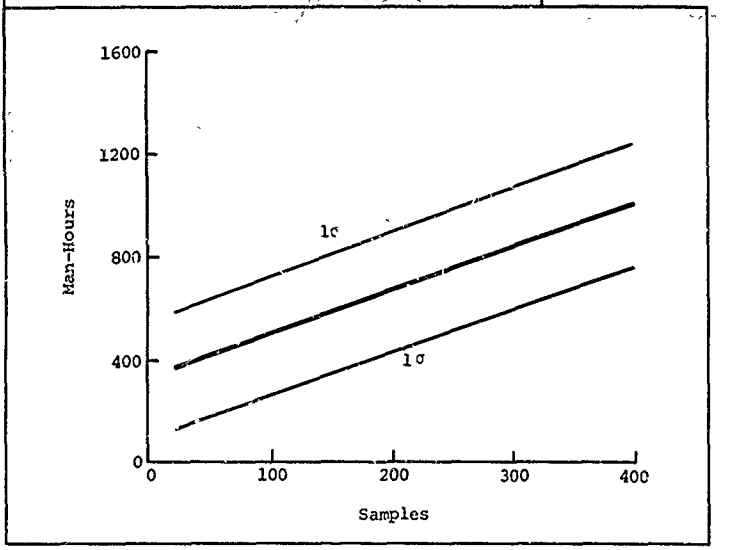
SUB-NOTE 1(16) Data Collection and Analysis



SUB-NOTE 1 (17) Σ Maintainability Tasks



SUB-NOTE 1 (18) Σ Demonstration Conduct and Report



DESIGN NOTE 1B6 MAINTAINABILITY RELATED SUPPORT FUNCTIONS

1. MAINTENANCE ANALYSIS (See DN 1B2, SN 1 (1), block 340.)

1.1 General

Maintenance analysis is a function by which maintenance requirements are projected, analyzed, and defined to ensure that all aspects of integrated logistic support are considered throughout the life cycle. This functional process begins with data accumulated from the maintainability analysis activities and design requirements developed during the Conceptual and Validation Phases. The maintenance analysis activities influence the formulation and the acquisition of required logistic resources.

The procuring activity usually provides a broad maintenance philosophy that the contractor will develop in detail. (See Chapter 10 for further direction in determining an appropriate maintenance concept.) The maintenance concept is the product of the initial maintainability design effort. As hardware is better defined, and the total analysis effort encompasses additional resources of maintenance (skills, tasks, number of personnel, tools, facilities), the contractor will evolve a detailed maintenance plan for the system.

The maintenance concept, the maintainability analysis, and the detailed maintenance plan are all highly interdependent efforts. Therefore, if the effort is divided, with different groups responsible for particular segments, close cooperation, good communication, and interchange of data are imperative.

1.2 Logistic Resources

The maintenance analysis is conducted to consider the following specific resources:

1.2.1 Equipment Publications (T.O.) (See DN 1B2, SN 1 (1), block 341.)

Equipment publication requirements are determined during the maintenance analysis. These requirements are based on the maintenance concept and on guidance provided by the customer. In addition, the customer directs how the

technical data developed by the contractor is interfaced with data on customer-furnished materiel. Source data gathered in the maintenance analysis is useful in determining detailed technical requirements for narrative material in the technical publications. Compatibility with actual equipment is the objective, regardless of the source of initial information.

1.2.2 Spares (See DN 1B2, SN 1 (1), block 342.)

Maintenance analysis data provides the basic technical data required for provisioning. When preparing provisioning requirements, it should be recognized that much provisioning data has been generated by previous activity and is included in the maintenance analysis data. The analysis data determines the repair parts selection, allocation, direct exchange, and maintenance float requirements. These inputs are used to determine provisioning requirements and develop provisioning and procurement recommendations.

1.2.3 Facilities (See DN 1B2, SN 1 (1), block 344.)

The maintenance performed at each category of maintenance is analyzed to determine requirements and criteria for special maintenance facilities, such as electrical-electronic shop, structures shop, calibration shop, and other work, test, or tuneup areas peculiar to the system. These requirements are identified in the Validation Phase as a result of the maintainability analysis. During the Full-Scale Development Phase, definitive requirements are developed and those requirements for new or modified facilities are acted upon.

1.2.4 Personnel and Training (See DN 1B2, SN 1 (1), blocks 345 and 343.)

The maintenance analysis provides the basic input data for the QQPRI effort at each level of maintenance.

1.2.5 Support Equipment (AGE) (See DN 1B2, SN 1 (1), block 346.)

Maintenance engineering analysis evaluates the support, test, measurement, and diagnostic equipment and calibration requirements. Based on the analysis of the system requirements and the resultant trade-offs, the support equipment requirements are determined.

1.2.6 Transportation (See DN 1B2, SN 1 (1), block 347.)

Transportation requirements are considered and design changes evaluated to eliminate special requirements such as special escort requirements for safety, security, storage, and handling. Transportation costs are considered in alternate design trade-offs.

1.2.7 Calibration Requirements Summary (See DN 1B2, SN 1 (1), block 348.)

Calibration requirements are identified for AGE, operational equipment, and training equipment. Costs of calibration requirements are included in the design trade-off analysis.

DESIGN NOTE 1B7 MAINTAINABILITY RELATED SYSTEM DESIGN DATA

1. DESCRIPTION

At the beginning of the Validation Phase, the functional baseline must be transformed into a system hardware baseline by the systems engineering function. The first step is to define the breakout of end items which satisfy the functional baseline requirements and then describe each end item in terms of the following dimensions to serve as a starting point for the conduct of the maintainability program tasks:

a. Type - Digital versus analog, computer versus communications, etc.

b. Complexity - Both the hardware and functional complexity data is required.

c. Accuracy - In the case of analog systems, input-output transfer function accuracy (tolerance) requirements must be given. For digital systems, this relates to the number of bits per word.

d. Environment - The operational environment must be determined and expressed in terms of climatic and shock and vibration dimensions.

e. Reliability - Predictions of operating, nonoperating, and normalized failure rates are required.

All the above data is continually updated through a constant iteration process by all disciplines until completion of design at the end of the Full-Scale Development Phase.

SECTION 1C

SAMPLE SYSTEM

This section contains a description of the Multiplexer Set. This system will be used in subsequent chapters to illustrate the guidelines, methodology, and procedures described in this notebook.

SECTION 1C SAMPLE SYSTEM

DESIGN NOTE 1C1 - THE MULTIPLEXER SET

1. EQUIPMENT DISCRIPTION

1.1 General

1.2 Operating Functions

2. OPERATING CHARACTERISTICS

2.1 General

2.2 Multiplexer

2.3 Demultiplexer

2.4 Configuration

3. DESIGN CHARACTERISTICS

3 (1) Multiplexer Set Printed Circuit Cards

4. MULTIPLEXER SET DEPLOYMENT

5. MULTIPLEXER SET REQUIREMENTS OUTLINE

5 (1) Requirements Specification

DESIGN NOTE 1C1 THE MULTIPLEXER SET

1. EQUIPMENT DESCRIPTION

The Multiplexer Set is an Air Force development item and will be referred to throughout this notebook to present examples of some of the maintainability tasks.

1.1 General

The Multiplexer Set is applied in a defense communications system for combining digital channels into a single, time-division multiplexed, digital data signal. The first application of the Multiplexer Set is expected to be in a satellite communications system. Satellite access and short haul high density applications also will involve TDM transmission over wideband ground links. The wide variety of data which must be accommodated to service the many DCS users properly results in a wide range of the number of channel inputs to a multiplexer; it further requires the capability to cascade multiplexer sets to reach high rates for efficient link loading.

1.2 Operating Functions

The Multiplexer Set provides asynchronous time division multiplexing (ATDM) and demultiplexing capabilities. The multiplexer portion accepts various lower rate digital input streams and interleaves them into a single higher digital stream The demultiplexer portion accepts a high-speed digital stream, with associated timing, and disassembles it into a number of lower rate digital streams. The multiplexer set provides full duplex operation, performing independently and simultaneously the multiplexer and demultiplexer functions.

An integral part of the multiplexer set is the diagnostic capabilities integrated into the equipment. These capabilities are basically divided into two functions· an on-line function which automatically isolates a malfunction

during equipment operation and indicates on the equipment front panels the location of the failed card or module, and a self-test function which is manually operated and isolates a malfunction in the diagnostic hardware and indicates on the equipment front panels the location of the failure.

2. OPERATING CHARACTERISTICS

2.1 General

The multiplexer set has provisions for operation with different types of input data. It will operate at varying rates, depending upon the number of channels used, the input data rates, and the configuration of port strapping and internal timing selection used by the operator. The types of data that can be input to the multiplexer are data with associated timing at preferred rates, data with associated timing at nonpreferred rates, and data without timing at preferred rates.

The data and timing rates for the multiplexer and demultiplexer are described below.

2.2 Multiplexer

a. Input Data Rates - 75 bits per second to 3.0×10^6 bits per second. Rate deviation not to exceed $\pm$ 250 parts in 10^6 of assigned nominal.

b. Output Data Rates - 155 bits per second to 10^7 bits per second. Rate deviation not to exceed one part in 10^6 of assigned nominal.

c. Reference Timing - 155 bits per second to 10^7 bits per second, adjustable to one part in 10^7 of assigned nominal.

2.3 Demultiplexer

a. Input Data Rates - Same as multiplexer output rates.

b. Output Data Rates - Same as multiplexer input rates.

c. Internal Timing - Derived from input data stream.

2.4 Configuration

Since varied input data rates can be applied simultaneously to different input channels, the equipment is provided with port strapping and internal timing rate selection capabilities. This allows for selection of the proper configuration which will provide the greatest efficiency of operation.

3. DESIGN CHARACTERISTICS

The multiplexer set is housed in two dip-brazed aluminum drawers, one for the multiplexer and another for the demultiplexer. Each measures approximately 26-7/32 inches high for a total height of 52-7/16 inches. The 17-1/4-inch width makes the equipment suitable for standard 19-inch relay rack mounting. Chassis slides are mounted on each side of the drawers. When the drawers are extended, they may be tilted $\pm 45°$ and $\pm 90°$.

Frequently used controls and indicators are mounted on a front panel. Wires from the front panel components are routed to the internal electronics through connectors which are mounted in a secondary panel directly behind the front panel.

Electronic circuits are largely comprised of integrated circuit devices and are mounted on edge-loaded cards which plug into a common wiring plane. A total of 31 card types are used in the multiplexer set. Of these types, nine are common to both the multiplexer and demultiplexer units. SN 3(1) is a listing of card types by name and unit application.

The multiplexer rate comparison buffer card (RCB) may be replaced by a source rate to transmission rate converter card (STRC) or a transition encoder card (TE). The demultiplexer smoothing buffer card (SB) may be replaced by a transmission rate to source rate converter (TSRC) or a transition decoder card (TD).

SN 3(1) Multiplexer Set Printed Circuit Cards

	Name	Used In
1)	Power Supply Monitor	MUX/DEMUX
2)	MUX Lamp Driver	MUX
3)	Overhead Enable Generator	MUX/DEMUX
4)	Strapping Switches	MUX/DEMUX
5)	Port Sequencer	MUX/DEMUX
6)	Sequencer Diagnostics	MUX/DEMUX
7)	Channel Sequencer	MUX/DEMUX
8)	Gated Clocks	MUX/DEMUX
9)	Reference Timer	MUX
10)	Data Multiplexer	MUX
11)	Oscillator Carrier	DEMUX
12)	Distribution Matrix	DEMUX
13)	Divide-by-n Counter No. 1	DEMUX
14)	Divide-by-n Counter No. 2	DEMUX
15)	Synthesizer Distributor	DEMUX
16)	Frame Sync	DEMUX
17)	Variable Length Shift Register	DEMUX
18)	Channel Monitor	MUX/DEMUX
19)	On-Line Maintenance	MUX/DEMUX
20)	MUX Remote Alarm	MUX
21)	Frequency Synthesizer	DEMUX
22)	DEMUX Lamp Driver	DEMUX
23)	DEMUX Remote Alarm	DEMUX
24)	Rate Comparison Buffer (RCB)	MUX
25)	Source to Transmission Rate Converter (STRC)	MUX
26)	Transition Encoder (TE)	MUX
27)	Smoothing Buffer High Speed (SBHS)	DEMUX
28)	Smoothing Buffer Low Speed (SBLS)	DEMUX
29)	Transmission to Source Rate Converter (TSRC), High Speed	DEMUX
30)	Transmission to Source Rate Converter (TSRC), Low Speed	DEMUX
31)	Transition Decoder (TD)	DEMUX

The line drivers and line receivers are hybrid microelectronic circuits which are assembled into enclosed, RFI sealed metallic modules. Each module contains two line receiver circuits or two line driver circuits. Thirty-three modules are mounted on the back of the multiplexer drawer and 32 on the demultiplexer drawer. On the multiplexer, 31 of the modules are line receiver modules (total of 62 line receiver circuits), one is a line driver module (total of two line driver circuits), and one is an external timing receiver module. On the demultiplexer, 31 of the modules are line driver modules (total of 62 line driver circuits), and one is a line receiver module (total of two line receiver circuits). The wires from the modules are routed into the chassis through EMI filters.

The multiplexer and demultiplexer both contain redundant power supplies. Power distribution between power supplies, wiring plane, and modules is by means of laminated bus bars. The supplies are located under the upper access cover, which is withdrawn from the front of the chassis.

Each multiplexer and demultiplexer chassis incorporates a cooling blower which draws air from the front of the equipment, and from the rear of the equipment, via the line driver and receiver module area. Cooling air entering the drawer internals is routed through filters located at the top and bottom of the chassis front panel.

The packaging arrangement uses a hinged front panel via which printed circuit boards are accessed.

4. MULTIPLEXER SET DEPLOYMENT

a. Equipment deployment to a large number (100 or more) of geographical locations is anticipated.

b. These locations will be worldwide.

c. Average equipment quantities will be four to five per deployment location, but may be considerably higher in specific instances.

d. Installations at the expected deployment locations will be a mixture of central office facilities and transportable trailer-type vans.

e. Maintenance of the equipment while on line is desirable and is acceptable.

f. Corrective maintenance will be performed on an as-required basis. Preventive tasks will be scheduled.

5. MULTIPLEXER SET REQUIREMENTS OUTLINE

a. Maintain a 99% availability in one up/down satellite link.

b. Operate continuously, with an MTBF of 2200 hours.

c. Have continuous knowledge of link operational status.

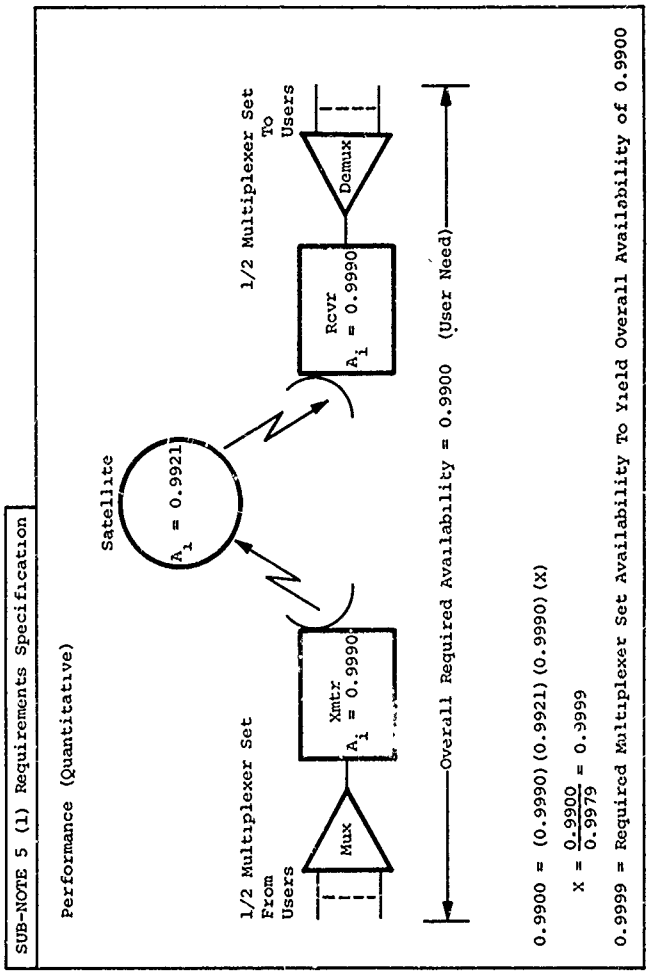
d. Perform maintenance with operator skill levels.

$$A_i = \frac{MTBF}{MTBF + \overline{M}_{ct}}$$

$$0.9999 = \frac{2200}{2200 + \overline{M}_{ct}}$$

$$\overline{M}_{ct} = 0.2 \text{ hour or } 12.0 \text{ minutes}$$

e. SN 5 (1) depicts the related requirements.


SUB-NOTE 5 (1) Requirements Specification
Performance (Quantitative)
Satellite
A_i = 0.9921
1/2 Multiplexer Set From Users
Mux
Xmtr A_i = 0.9990
1/2 Multiplexer Set To Users
Rcvr A_i = 0.9990
Demux
Overall Required Availability = 0.9900 (User Need)
0.9900 = (0.9990) (0.9921) (0.9990) (X)
X = 0.9900 / 0.9979 = 0.9999
0.9999 = Required Multiplexer Set Availability To Yield Overall Availability of 0.9900

CHAPTER 2

ROOTS OF MAINTAINABILITY

This chapter defines maintainability by describing its roots, their dimensions and applicability. The roots of maintainability are fault location, packaging, accessibility, interchangeability, adjustments, standardization, and preventive maintenance. All roots are applicable to all types and levels of ground electronic systems hardware at all maintenance levels. Guidance in determining "how much" of each root is covered in Chapter 9 and the establishment of general trends for each root is covered in Chapter 13. Also included is design data relative to fault location.

CHAPTER 2 ROOTS OF MAINTAINABILITY

SECTION 2A - INTRODUCTION TO THE ROOTS OF MAINTAINABILITY

Design Note 2A1 - Fault Location
2A2 - Packaging
2A3 - Accessibility
2A4 - Interchangeability
2A5 - Adjustments
2A6 - Standardization
2A7 - Preventive Maintenance

SECTION 2B - MAINTAINABILITY ROOTS DESIGN IMPACT

Design Note 2B1 - Fault Location by Integral Sensor Tests

SECTION 2A

INTRODUCTION TO THE ROOTS OF MAINTAINABILITY

This section contains the definition, description, dimension, and applicability of each of the roots of maintainability.

SECTION 2A INTRODUCTION TO THE ROOTS OF MAINTAINABILITY

DESIGN NOTE 2A1 - FAULT LOCATION

1. DEFINITION AND DESCRIPTION
2. FAULT LOCATION REQUIREMENTS
3. DIMENSIONS
4. APPLICABILITY

DESIGN NOTE 2A2 - PACKAGING

1. DEFINITION AND DESCRIPTION
2. DIMENSIONS
3. APPLICABILITY

DESIGN NOTE 2A3 - ACCESSIBILITY

1. DEFINITION AND DESCRIPTION
2. DIMENSIONS
3. APPLICABILITY

DESIGN NOTE 2A4 - INTERCHANGEABILITY

1. DEFINITION AND DESCRIPTION
2. DIMENSIONS
3. APPLICABILITY

DESIGN NOTE 2A5 - ADJUSTMENTS

1. DEFINITION AND DESCRIPTION
2. DIMENSIONS
3. APPLICABILITY

DESIGN NOTE 2A6 - STANDARDIZATION

1. DEFINITION AND DESCRIPTION
2. DIMENSIONS
3. APPLICABILITY

DESIGN NOTE 2A7 - PREVENTIVE MAINTENANCE

1. DEFINITION AND DESCRIPTION
2. DIMENSIONS
3. APPLICABILITY

DESIGN NOTE 2A1 FAULT LOCATION

1. DEFINITION AND DESCRIPTION

There are several fault location categories, as listed below:

- Automatic hardware, external
- Automatic software, external
- Automatic hardware, internal
- Automatic software, internal
- Manual software
- Manual
- Semiautomatic (combination of manual and automatic)

The term automatic indicates that the testing is performed without human intervention.

Hardware testing means that the input(s) to a function may be provided a stimuli and the output(s) are monitored. The level of isolation is therefore just to that function.

Software testing still requires stimuli and monitoring, but a predetermined logical analysis is applied to the results of the input/output relationship and isolation is to a lower level than that in hardware testing only (given the same input(s) and output(s)). Another way to say this is that for a given level of fault location, fewer test points are required for software testing compared to hardware testing, but a software program is required.

Internal test equipment, usually referred to as Built-In Test Equipment (BITE), is obviously special-purpose equipment; that is, it is built to perform a specific test function or functions on a particular equipment or equipments.

External test equipment can be either general purpose or special purpose. (General purpose equipment is built for general test functions on many equipments and includes such items as signal generators, meters, scopes, etc.).

Manual testing is basically the utilization of standard commercial test equipment and some degree of "trial and error" techniques and generally results in some unacceptable degree of indiscrimate substitution and making adjustments to attempt a quick fix.

It should be pointed out that the fault detection (i.e., performance monitoring) features in equipments and systems are not included for maintainability, but are provided primarily to inform operating personnel of the operational status of sections of the equipment or system. Therefore, selection of the system parameters to be monitored and the monitoring technique to be used are not primary maintainability design considerations.

If performance monitoring features are included in a system design, they can be used as the starting point for fault isolation because they will generally provide some degree of fault location.

The normal operational indications provided in a system also provide some degree of fault location so that the starting point for fault location, particularly at the system level, is not zero.

2. FAULT LOCATION REQUIREMENTS

Fault location requirements are dictated to some extent by the test approach selected for the equipment or system. However, in any fault location scheme, it is necessary to provide access points or sensing design by which the adequacy of circuit operations can be determined. The electronic and physical locations and the numbers or these access or test points are the primary factors to be considered for fault location. DN 2B1 presents an analysis of test point and sensing design, pointing out the advantages and disadvantages of various techniques.

3. DIMENSIONS

In addition to maintenance time, diagnostic effectiveness is possibly one of the most significant yields by which a fault location system is measured. It is the product of its components; i.e., resolution and percentage of failures for which that resolution is applicable (comprehensiveness). This is expressed as:

$$DE = RC$$

Where R = Resolution = $1 - \frac{\text{Average callout size}}{\text{total size}}$ and C = Comprehensiveness.

The average callout size and the total size must be in the same dimension; i.e., piece parts or cards or chassis, etc.

4. APPLICABILITY

Fault location is applicable to all types and levels of ground electronic hardware down to the discard-at-failure level. The most common application of mechanized software programs is to digital equipment.

DESIGN NOTE 2A2 PACKAGING

1. DEFINITION AND DESCRIPTION

There are three packaging characteristics of interest to the maintainability discipline.

a. Structuring - This relates to the number and complexity of each hardware level which comprises the system, down to and including the DAF level.

b. Classification - The relationship of the components within a package, at each hardware level, is an important maintainability characteristic. There are two basic classes: functional, wherein the package contains those parts which work together; and hardware, wherein the package contains those items which are alike or identical but which do not necessarily work together. Functional packaging can be defined as that grouping of hardware in each package which results in the least total number of interconnections between packages at all levels of hardware.

c. Mounting - This is divided into two basic types: plug-in or hardwired. Mounting is an important packaging characteristic that is covered in detail in DN 2A3.

2. DIMENSIONS

The packaging structuring and classification contribute to the malfunction isolation time, and therefore these two characteristics of packaging are included in DN 2A1.

3. APPLICABILITY

Packaging is applicable to all types of hardware.

DESIGN NOTE 2A3 ACCESSIBILITY

1. DEFINITION AND DESCRIPTION

Accessibility pertains to the time and other logistics resources necessary to gain access to the hardware in order to conduct maintenance in terms of inspection, test, repair, remove, and replace actions.

The extent to which consideration has been given to hardware stacking, types and numbers of fastening devices, types of interconnection devices, and manual dexterity requirements determines accessibility.

2. DIMENSIONS

Accessibility is measured in terms of time and AGE (tools) required to gain access for maintenance purposes.

3. APPLICABILITY

For ground electronic systems, structural access doors (load carrying) are not considered reasonable candidates.

DESIGN NOTE 2A4 INTERCHANGEABILITY

1. DEFINITION AND DESCRIPTION

Fully interchangeable items are those items having the same manufacturer's or Federal Stock Number (FSN), which, when interchanged or substituted for each other without modification, adjustment, or selection, will provide the same physical and functional characteristics required of the original item. Interchangeable items above the piece part level may contain adjustable electrical or mechanical piece parts, provided they are the "factory set and sealed" type and such interchangeable items can be purchased for spares purposes in a preset and sealed configuration. Fully interchangeable items require no adjustment of the equipment or assembly in which they are used.

Examples or classes of noninterchangeability are select fits, matched pairs, and items requiring adjustment or modification of the item or the system in which it is used after replacement.

As a corollary item to interchangeability, items which are not functionally interchangeable should not be physically interchangeable, except for items which are considered interchangeable after adjustment.

2. DIMENSIONS

The measure of interchangeability is a count of the noninterchangeable items in the system and the logistics resources required to perform the maintenance actions on each.

3. APPLICABILITY

All items at all levels of hardware should be interchangeable in digital* hardware, and the presence of a noninterchangeable item should be a possible candidate in analog hardware only.

*The term digital, as used in this notebook, refers only to the binary elements of a digital system and not the analog portions, such as A/D's and D/A's.

DESIGN NOTE 2A5 ADJUSTMENTS

1. DEFINITION AND DESCRIPTIONS

Adjustments are defined as any mechanism by which an item may be brought into proper position or condition (tolerance). Adjustments are made to produce a desired response from a given stimulus or to accomplish an electrical functional fit.

Interacting adjustments are two or more adjustments which affect a single parameter or response of an item.

An adjustment that is a one-time-only, "factory set and sealed" type which does not constitute a maintenance requirement during equipment employment is not considered to be an adjustment from the maintainability standpoint.

The presence of an adjustment, other than the factory set and sealed type, implies that an item must be adjusted on a periodic basis in order to keep the system operating within its required tolerance. If an adjustment is not made on a preventive basis, but rather on a corrective basis because the system has become out of tolerance, the maintenance rate of the system is increased because this is not normally considered in reliability calculations.

2. DIMENSIONS

The measure of adjustments is a count of the adjustments and a measurement of the time and other logistics resources required to perform the adjustments.

3. APPLICABILITY

The presence of adjustments is only a viable candidate in analog electronic equipment, and not in digital electronic equipment.

DESIGN NOTE 2A6 STANDARDIZATION

1. DEFINITION AND DESCRIPTION

Standardization is the discipline dedicated to two principles: utilization of a maximum number of identical parts in a system, and utilization of a maximum number of off-the-shelf parts in a system. This can be defined as intrasystem and intersystem standardization.

From a maintainability standpoint, utilization of nonstandard parts below the discard-at-failure level has little impact.

2. DIMENSIONS

The measure of standardization is a count of the nonstandard items in the system, and a count of the nonmilitary standard items in the system. This is applicable to all levels of hardware to the discard-at-failure level.

3. APPLICABILITY

Standardization is applicable to all levels and types of hardware. Standardization at the higher levels of hardware is generally easier to achieve and more cost effective in digital equipment.

DESIGN NOTE 2A7 PREVENTIVE MAINTENANCE

1. DEFINITION AND DESCRIPTION

Preventive maintenance is defined as the composite of those maintenance actions performed on a periodic basis. The period may be based on calendar time, operating time, equipment cycles, etc.

The elements of preventive maintenance, as applicable to ground electronic systems, are as follows:

a. Time Replacements - Items which have a shelf life or experience time, cyclic, or wear degradation and must be replaced at specific intervals to maintain the required tolerances of the system.

b. Filter Replacements - All filtering elements which require periodic replacement or cleaning. Permanent, self-cleaning, filters which require no additional maintenance actions are excepted.

c. Lubrication Points - Those points where lubricants grease, oil, etc., are introduced into the unit. Permanently lubricated bearings or assemblies are not included.

d. Inspection - A post-manufacture examination of a unit to determine its condition and fitness to perform its intended function or to scrutinize it for susceptibility to malfunction.

e. Periodic Test - Any test or checkout operation which must be performed on a scheduled basis.

f. Calibration - Determination of the value of characteristics of an item by comparison with a standard. Items found to be outside prescribed tolerances may or may not require adjustment.

2. DIMENSIONS

Preventive maintenance is measured by the count of preventive maintenance actions required and the value of the peculiar logistics resources required to perform them; i.e., manpower, AGE, etc.

3. APPLICABILITY

For electronic equipment, the most significant preventive maintenance action is calibration. Calibration requirements are only applicable to analog electronic equipment.

Any preventive maintenance action which can be scheduled in a period when the equipment is not required operationally or which can be performed while the mission is being fulfilled does not contribute to downtime.

SECTION 2B

MAINTAINABILITY ROOTS DESIGN IMPACT

This section provides information on the design of fault location systems (hardware type). It contains an analysis of an integral sensor test system, including determination of the numbers and locations of test points to permit fault location at a high level of confidence.

SECTION 2B MAINTAINABILITY ROOTS DESIGN IMPACT

DESIGN NOTE 2B1 - FAULT LOCATION BY INTEGRAL SENSOR TESTS

1. GENERAL

2. INTEGRAL SENSOR TEST SYSTEM (ISTS) OPTIMIZATION

2.1 Analysis of Basic Configuration

2.1.1 Introduction

2.1.2 Option 1

2.1.3 Option 2

2.1.4 Trade-Off Analysis

2.1.5 Conceptual Description of Recommended ISTS

2.1.5 (1) Conceptual Illustration of an Air Force Site With an ISTS

2.2 Sensor Designs

2.3 Evaluator Design

2.3.1 Thresholding Considerations

2.3.2 Fault Detection and Diagnosis

2.4 Display Design

2.4.1 Local Display

2.4.2 Centralized Display

2.5 Depth of Isolation

2.6 Fault Prediction

2.7 Test Point Selection

2.7.1 Failure Rate Establishment

2.7.1 (1) Example of Prime Equipment

2.7.1 (2) LRU Inputs/Outputs

2.7.1 (3) LRU Input/Output Relationships

2.7.2 Fault Code Establishment

2.7.3 Interdependency Establishment

2.7.3 (1) Example Synchronizer

2.7.4 Evaluation of a Particular Sensor

2.7.5 Evaluation of a Sensor Set

2.8 Analog Sensors

2.8 (1) Analog Signal Amplitude Sensors

DESIGN NOTE 2B1 FAULT LOCATION BY INTEGRAL SENSOR TESTS

1. GENERAL

The Integral Sensor Test System (ISTS) is a form of built-in test that can measure and evaluate basic electronic parameters on a continuous on-line monitoring basis. The recommended ISTS concept is to perform localized processing within each prime equipment. Centralized display and mode control are an optional part of the ISTS, since display and mode control are also possible at the prime equipment level. Essentially, one can consider the sensors within an equipment as a nerve network and the decision was to also place the "brain" (evaluator) within the prime equipment. This is a more cost-effective technique since the sensors can be utilized independent of auxiliary equipment.

Sensors are described that can efficiently sense basic electronic parameters such as AC, DC, pulse, frequency, phase difference, etc. The sensors are in microelectronic form and can be used as standard sensors for the parameters and signal levels for which they were designed, but are versatile enough to allow applicability to a variety of frequencies, pulses, and signal levels which put simple variations in component values. An analytical methodology is also described that allows the designer to determine the numbers and locations of test points to permit fault isolation at a high confidence level.

Guidelines and results that can be obtained through the use of the described technique are as follows:

a. A relatively simple, but effective integral sensor test system can be designed into systems to provide quick and effective fault isolation at a high confidence level.

b. An integral sensor test system should be confined to the equipment level, when practical, as opposed to a centralized system evaluator and display, to minimize the need for highly complex multiplexing and cabling that would substantially increase costs and decrease reliability.

c. The relative complexity of the sensor/evaluator should be less than 10 percent of the final equipment. This level of complexity will permit a 90- to 95-percent detection/isolation capability and will limit the impact of increased cost, size, weight, and reliability of the final equipment.

d. Sensors should be designed as an integral part of the prime equipment, since it enhances compatibility between sensors and systems design and allows the sensors to utilize power from the prime equipment to minimize interconnections and reduce size and cost.

e. Sensor signal evaluation should be performed at a level where a number of LRU's form a functional entity within a larger system thus utilizing the "virtual" test point concept.

f. Thresholding of the sensed signal should be performed at the evaluator, and the evaluator should be powered by a separate power source to maintain coherent output in the event of power supply failures.

g. The evaluator should be designed to isolate single faults only, since evaluation of multiple faults has shown to be not cost effective.

2. INTEGRAL SENSOR TEST SYSTEM (ISTS) OPTIMIZATION

2.1 Analysis of Basic Configurations

2.1.1 Introduction

One of the basic decisions relative to the design of the ISTS is the level at which the evaluation of sensor data should be performed. The extremes are:

- Thresholding the sensor within each LRU.
- Transmitting the sensor data to a centralized evaluator (i.e., a computer) where the sensors from a number of prime equipments are thresholded, digitized, and evaluated.

Neither extreme is desirable, and there is a logical level for performing the required evaluation.

2.1.2 Option 1

The first option for evaluation of individual sensors within the LRU is obviously too elementary. Such an approach denies the use of deduction, which is a powerful tool for minimizing the number of sensors. In some cases, a fault within a particular LRU can be isolated to a high degree of accuracy even though there is no sensor within it. For example, imagine a system with a number of integrators, each in a separate LRU. Next assume that there is an associated LRU that generates a set of switching signals to reset the integrators, and assume that this LRU has no sensors in it. If sensors on the outputs of all the integrators suddenly indicate saturation, there are two likely causes; i.e., a failure in the reset circuitry or simultaneous failures in each of the integrators. Common sense dictates that one should assume that the reset LRU has failed. The literature makes reference to a "virtual test point" at the output of the reset LRU described above. It is therefore apparent that evaluation at too low a level does not realize the full potential of the integral sensor approach.

2.1.3 Option 2

The second option for evaluation of all sensor data at a level as consolidated as possible has certain merits. Some of the positive factors are:

- Redundancy in the installation is eliminated by commutating a programmable evaluator between several prime equipments.
- The evaluator can be quite flexible and complex, since only one evaluator is required for a given installation.
- All mode control and display are inherently centralized.
- Further refinements such as fault prediction, trend analysis, and automatic repair could be realized with this type of evaluator (i.e., computer).

At the same time, however, there are some negative factors associated with centralized evaluation, including the following:

- All sensor data must be interconnected to the evaluator. Particularly in microelectronic equipment, the connectors and cabling could easily become a significant, if not dominant, item.
- The large number of interconnections can be reduced by multiplexing, but the complexity remains high and there may be accuracy problems due to offset in the multiplexer.
- The resultant flexibility is low, since the sensor network can only be utilized for automatic fault isolation when the system is operated in an installation where there is an evaluator available.
- When the evaluator is down, the entire installation is severely compromised.
- Fault data generated within a centralized processing area must be transmitted back to localized displays for use by maintenance men.

These factors should be carefully weighed during the program to determine the negative factors and the positive factors.

2.1.4 Trade-Off Analysis

The question of where to perform the evaluation therefore remains. The solution is to look at the functional interrelationships of groups of LRU's within a prime equipment. Eventually, one will reach a level of hierarchy where the LRU's in a particular group are interrelated in themselves but are relatively isolated (functionally) from other LRU's or groups of LRU's. At this level, the potential for deductive evaluation is totally realized, and the evaluation can just as well be performed there.

One of the advantages of this approach is that interconnections are minimized, since the evaluator will always be in the immediate vicinity of the associated LRU's. The evaluator can, itself, be an LRU in the system. Each evaluator can be envisioned as a hard-wired evaluator (as opposed to programmable) for that specific application.

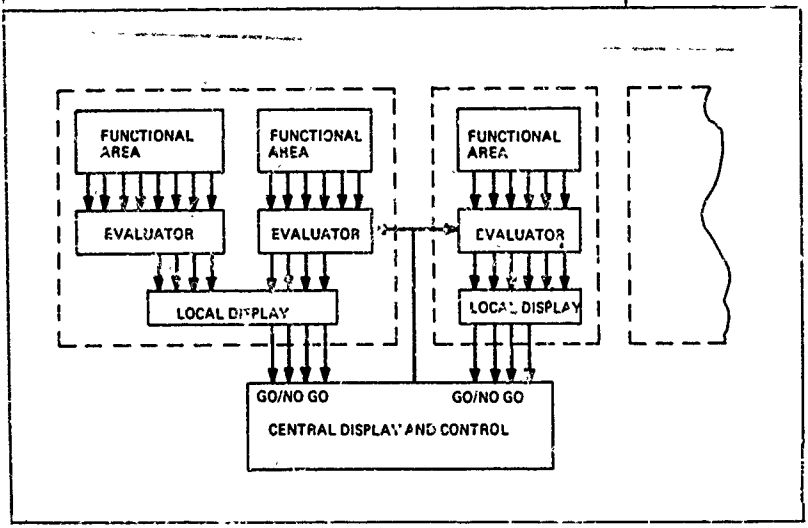
Another attractive feature of this ISTS concept is that there is an optimum versatility. The sensor network can be utilized even when a particular prime equipment is used individually, yet it is completely compatible with even the largest installations. The sensors can be viewed as a "nerve network" within the equipments and the evaluator as the "brain". With the "brain" at or within the prime equipment, it can obviously function individually or in a group.

2.1.5 Conceptual Description of Recommended ISTS

The recommended level of evaluation described above essentially defines a basic ISTS configuration. A number of additional details was also evolved to more completely describe the system. A conceptual diagram of the ISTS is shown in SN 2.1.5 (1). The dashed lines in SN 2.1.5 (1) indicate boundaries of prime equipment. The first equipment is a system to modest proportions having two functionally independent areas. An example of such a system might be a transceiver. One evaluator is designed around the transmitter and another around the receiver. The reason this is the appropriate level is that there are few interrelationships between LRU's in the transmitter and receiver. Within the transmitter subsystem, however, there are interrelationships involving keying signals, mode control signals, AFC loops, etc. A second evaluator is designed around the receiver. Each evaluator then generates go/no-go signals for each LRU with which it is associated. Every evaluator should also generate a go/no-go summary indication for its functional area. The outputs from the two evaluators are combined into a common local display. Signals are also provided on a standard auxiliary connector for use in a centralized display area.

Another prime equipment in the ISTS conceptual diagram of SN 2.1.5 (1) is shown with only one major functional area. The concept is essentially the same, however. Sensors within the LRU's generate outputs which are thresholded and processed in the evaluator. The evaluator generates go/no-go outputs for each LRU and a summary indicator for that system. The outputs of the evaluator are also provided on an auxiliary connector for use in a centralized display.

SUB-NOTE 2.1.5 (1) Conceptual Illustration of an Air Force Site With an ISTS



Other prime equipment in SN 2.1.5 (1) may involve several subsystems, and each subsystem will have an associated evaluator. For example, a radar may have transmitter, antenna, receiver, data processor, and display subsystems. The local ISTS display for that system would likely be located in the display subsystem but independent evaluators would be located in each subsystem.

The evaluators in SN 2.1.5 (1) may have a control to activate a fault prediction mode of operation. This control could be derived either from the central or local display area, with priority given to fault prediction to avoid opposing commands from the local and central areas. An indicator should also be provided on the display to indicate the selected mode.

2.2 Sensor Designs

The basic purpose of sensors within a prime equipment is to provide the evaluator with the essential information required to detect and isolate faults. The proper placement of sensors (test point selection) is discussed in paragraph 2.7, but it is important to recognize that sensor requirement in a particular application are established by the parameter(s) at the selected test points. Sensor design must not be a strong influence during test point selection, although there must be some feedback if a cost effective system is to be realized. The feedback should be minimized and it should deal primarily with the feasibility and cost effectiveness of sensors for particular parameters. For example, the selection of a test point must be discouraged if a reasonable sensor to monitor that parameter is not feasible conversely, to encourage the selection of a test point because the parameter is easy to sense or because there is an existing sensor could easily compromise the ability of the evaluator to detect and isolate faults. Cost effective sensors for most parameters can be realized without preempting test point selection.

When standard sensors are impractical, one design approach could be to generate standard electrical designs and/or circuit configurations so that the designer can select components compatible with the prime equipment requirement

and quickly implement a sensor. This approach to sensor design minimized interconnections because the sensor can always utilize whatever system power is available. There should never be a requirement for separate power supplies or special wiring for sensor because no advantage can be gained by powering sensors from an independent power supply.

This suggested approach to sensor design also assures complete compatibility with the prime equipment.

2.3 Evaluator Design

2.3.1 Thresholding Considerations

The function of the evaluator is to process the sensor data for the purpose of detecting and isolating faults. Most sensor data is analog but the simplest evaluator designs should result from digital processing. It is therefore recommended that the sensor data be immediately thresholded, if necessary in a high/low threshold circuit or "window detector."

2.3.2 Fault Detection and Diagnosis

a. General

After digitizing the sensor outputs, the evaluator must process the data for the purpose of detecting faults and isolating the faults to an LRU. A systematic technique for performing these functions is to consider the digitized sensor data as a composite logical word. Then the evaluator can be programmed to recognize all possible logic words and associate a "normal" or "failure and location of failure" with each word. The evaluator designer must therefore examine all possible fault codes and identify all those which he feels could occur. Some codes are totally impossible or could only occur with a number of simultaneous failures. After he has identified the fault codes which are possible, he must then associate the proper status or fault condition with each code.

b. Partitioning of Fault Codes

One of the problems with this technique is that there may be a very large number of possible fault codes. For example, in a system involving as few as 10 sensors, there are 1024 possible fault codes. Techniques must therefore be investigated to greatly reduce the number of potential fault codes. Three techniques are described in the following paragraphs.

The first technique is known as partitioning. Using this approach, one essentially breaks up a relatively long binary word into a number of shorter binary words. The sum of these shorter words is much less than the one composite word. For example, if a 10-bit word is partitioned into two 5-bit words, the codes are reduced from 1024 to

$$2^5 + 2^5 = 64.$$

The rationale for partitioning is very logical. For example, assume a system with 10 sensors with the first four sensors associated with the system power supplies. In examining fault codes, it is immediately apparent that a power failure is defined by a zero in one of the first 4 bits. All fault codes with one or more zeros in the first 4 bits uniquely defines a power failure. All permutations of the remaining 6 bits are therefore irrelevant. In fact, the sensor outputs of the last 6 bits are totally meaningless because the required supply voltages are not present. One is totally justified in partitioning the code word between the first 4 bits and the remaining 6 bits. The result is that the evaluator looks first at the first 4 bits and, if any zeros are present, a unique diagnosis can be made immediately. If all 4 bits are "1", then the evaluator proceeds to a second level or hierarchy and evaluates the permutations of the remaining 6 bits. The total number of codes to be evaluated is now

$$2^4 + 2^6 = 80.$$

It is therefore obvious that partitioning reduces the number of fault codes by a large amount.

c. Additional Techniques for Fault Code Reduction

The number of fault codes can also be reduced considerably by assuming that the evaluator will only have to perform under conditions of a single fault. The likelihood of simultaneous faults is far less than 1 percent, and therefore consideration of multiple faults and the corresponding fault codes is obviously not cost effective. The system designer must be conscious of multiple fault conditions whereby one fault is induced by another. Such a condition occurs most frequently in high-power systems. Using single fault assumption on the previous example, only four fault codes need be considered for the first 4 bits. Little can be said concerning the number of combinations of the remaining 6 bits that can only occur under multiple fault conditions. Based on previous experience, a conservative estimate is that half the codes can be generated only under multiple faults. Thus, the fault codes for the 10 sensor example are now reduced to

$$4 + \frac{2^6}{2} = 36 \text{ fault codes.}$$

This is a significant reduction from 1024 codes and these techniques are even more essential in larger systems. Additional partitions are very possible in larger systems and then evaluation can be conducted in three or more sequential operations.

Every evaluator should also be designed to provide a summary go/no-go indication for the LRU's with which it is associated. For small systems, this will be a go/no-go indication for the entire system, while in large systems, they will relate to major subsystems. In the latter case, provisions should be made to combine the summary indications from the major subsystems into a go/no-go indication for the entire system.

2.4 Display Design

2.4.1 Local Display

A local display (prime equipment level) should be provided so that the system can function independent of any auxiliary equipment. The local display design

should be compatible with the prime equipment, and therefore no general design can be recommended. At a minimum, the local display should include a go/no-go indicator for each LRU in the system, as well as all the summary indicators generated within the system. In a very large prime equipment, the designer may consider providing a local display on each cabinet. The only remaining requirement would be to display the summary indicators in a central area of the prime equipment. This approach reduces the number of interconnections between cabinets within the prime equipment.

All the evaluator outputs should also be made available on a separate connector in the prime equipment. These signals can be used when desired in a centralized display. In very large systems with several cabinets, the system designer may choose to provide a connector in each cabinet rather than consolidating them into a single connector.

2.4.2 Centralized Display

When a number of prime equipments are consolidated into a single installation, it will eventually be desirable to display the equipment status, failures, etc., in a central monitoring area. The degree of sophistication and flexibility of the centralized display cannot be logically defined at this point. The size, the layout, and the mission of the site all influence central display design. It is therefore recommended that a design or design approach be evolved as some of the first system prime equipments are evaluated. A likely solution is to develop a modular console with a high degree of flexibility.

Central display design can be as simple as a bank of lights and a few control switches. Of course, more compact displays (i.e., CRT's) could be provided with additional information such as block diagrams. Additional equipment could also be provided to record equipment status, to print out a hard copy of all failures, etc. These are but a few of the possible approaches to centralized display design, but they illustrate the range of possibilities which make standard designs impractical.

The amount of information provided by the centralized display should also remain open. Possible alternatives in this area are as follows:

a. Display all summary and LRU status indications

b. Display all summary indicators in one mode and all LRU status indicators for an operator-selected prime equipment in a second mode

c. Display only summary indicators and go to individual prime equipment for faulty LRU information

2.5 Depth of Isolation

One of the trade-offs relative to system design is how precise and to what level fault isolation should be performed. When the concept requires isolation to an LRU which is then replaced by a repairman, there is no benefit from isolation beyond the LRU. Isolation of faults within an LRU is therefore prescribed as an off-line function and a second hierarchy of integral sensors for this purpose is clearly not cost effective. With reasonable requirements for isolation accuracy (80 to 90 percent), experience indicates that the sensor population is approximately one per LRU.

Since there is typically one sensor per LRU, the complexity of the LRU establishes the ratio of prime equipment circuitry to sensor/evaluator circuitry. Typical LRU complexities in state-of-the-art equipment are such that the sensor and evaluator circuitry should constitute less than 10 percent of the overall system.

With a sensor population of approximately one per LRU, the system will detect and isolate 90 to 95 percent of the faults. Additional sensors will increase these percentages, but the cost effectiveness of the additional sensors may be too low to justify in most applications.

The above factors are essentially "engineering judgments" based on the experience gained during the program. The breadboard circuitry is typical of most electronic gear, and therefore the factors should apply to other equipment. As more experience is gained in the area these "rules of thumb" should be updated, but at present they are the best possible starting points.

2.6 Fault Prediction

The system maintainability failure indication occurs when one or more test point parameters in a given system exceed a prescribed threshold. By imposing more stringent thresholds on a particular parameter, it is possible to detect a degradation which may suggest an impending failure. Thus, one can suggest a second mode of operation for the system whereby certain thresholds are tightened and the "failures" indicated in this mode are predicted failures. There are a number of factors to be considered, however, before such an approach can be undertaken. Some of these considerations are as follows:

a. Digital sensor outputs do not degrade or drift but are essentially go/no-go.

b. It is difficult enough, in a few situations, to specify failure thresholds and attempting to be more discerning may be impractical.

c. Test points in control loops may be held constant even though there are degradations in the system. In this situation, additional sensors may be required for fault prediction.

d. There is a significant amount of added complexity in the threshold circuitry which may not be justified.

e. This mode may easily introduce a situation where the evaluator is faced with two or three simultaneous "failures" so that added evaluator complexity may also be required to provide adequate performance in a fault prediction mode.

2.7 Test Point Selection

One of the key requirements for implementing a cost effective design is proper test point selection. The sole purpose of integral sensors is to facilitate performance monitoring and fault isolation. It is therefore obvious that the location of these sensors (test point selection) must be based on the ability of the sensor(s) to detect and isolate faults in the prime equipment.

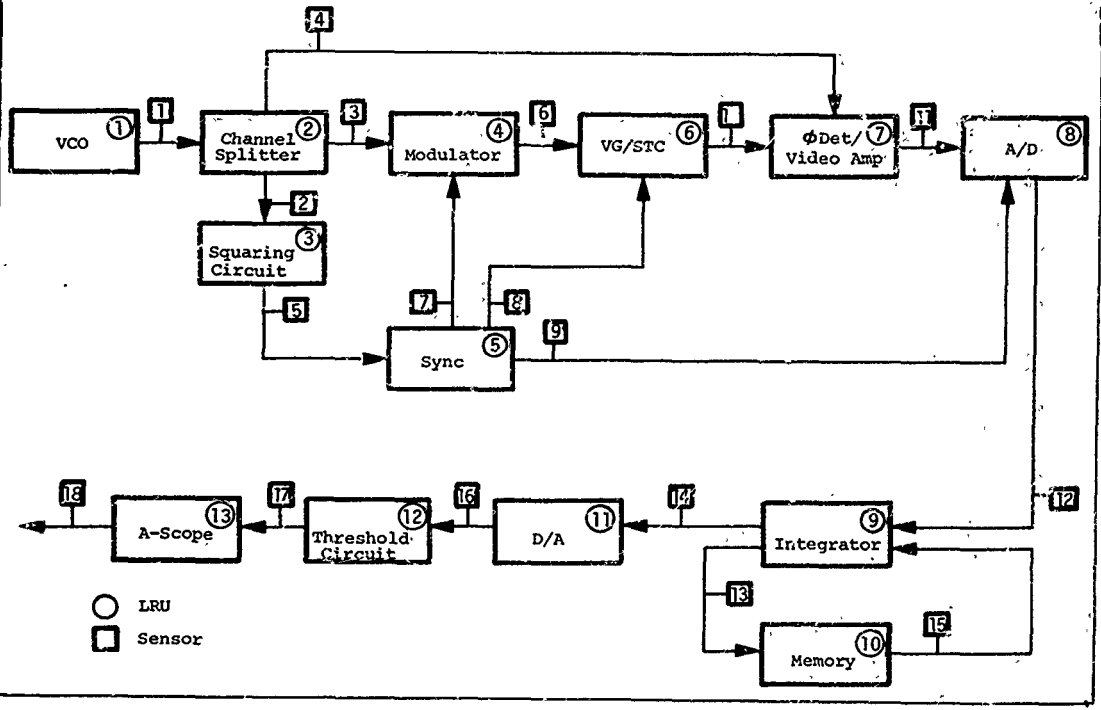
Two additional factors must also be considered during test point selection. First, test point selection should be biased so as to concentrate sensors in areas where failures are most likely to occur. A key element in test point selection is therefore the establishment of probability-of-failure data for each functional area in the system. It is important to note that the failure rates are used only in a relative sense to bias test point selection to the areas in the system that are more likely to fail.

Secondly, there is the question of how feasible a sensor is once a test point is selected. If the parameter at a particular test point is extremely difficult to measure, that test point should be avoided in the interest of a cost effective system even if two alternate test points are required. This should generally not be a problem since most parameters can be sensed with cost effective sensors. It is also important to note that test point selection should not be biased toward selection of specific test points to permit the use of existing or easily implemented sensors. The effectiveness could very quickly be compromised by such an approach.

2.7.1 Failure Rate Establishment

SN 2.7.1 (1) shows a functional block diagram of a system showing the interrelationships between the units. The system consists of the IF processing portions of a pulsed radar channel, including those items necessary to generate test signals. Included are a variable gain amplifier (VGA) with a sensitivity time control (STC), a phase detector, an A/D converter, a digital integrator, a D/A converter, and a threshold circuit driving the display scope. A VCO supplies the system IF signal, clock and COHO. The synchronizer controls

SUB-NOTE 2.7.1(1) Example of Prime Equipment



the timing for the system, generating the pulsed IF, the STC timing, and the A/D sample signals. For the sake of simplicity, the power supplies needed for these units are not included in the diagram although it can be readily seen that the supplies could be LRU's providing inputs on which the other units would be dependent. Each LRU can be specified according to its inputs and outputs (see SN 2.7.1 (2)).

SUB-NOTE 2.7.1 (2) LRU Inputs/Outputs

LRU	Name	Inputs (from)	Outputs (to)
1	VCO	-	2
2	Channel Splitter	1	3,4,7
3	Squaring Circuit	2	5
4	Modulator	2,5	6
5	Synchronizer	3	4,6,8
6	VGA, STC	4,5	7
7	ϕ Detector, Video Amplifier	2,6	8
8	A/D	5,7	9
9	Integrator	8,10	10,11
10	Memory	9	9
11	D/A	9	12
12	Threshold	11	13
13	A-Scope	12	-

A particular LRU can be defined as having failed if it does not provide a valid output in the presence of its valid inputs. By using established reliability data (e.g., MIL-HDBK-217A) and knowing the LRU internal electronics, the likelihood of the failure of a given LRU output can be expressed mathematically. The normalized failure rate of those portions of an LRU concerned with relating a given output to the LRU inputs can be taken as the probability that this output will fail. Thus, to describe the system, the input/output relationships of the LRU's listed in SN 2.7.1 (2) are shown in SN 2.7.1 (3).

SUB-NOTE 2.7.1 (3) LRU Input/Output Relationships

LRU	Output to LRU	Failure Rate x 10^{-6}	Input
1	2	13.1	
2	3	4.3	1
	4	4.3	1
	7	4.3	1
3	5	10.1	2
4	6	12.6	2,5
5	4	16.7	3
	6	18.0	3
	8	21.3	3
6	7	15.3	4,5
7	8	12.0	2,6
8	9	25.2	5,7
9	10,11	11.3	8,10
10	9	15.6	9
11	12	20.1	9
12	13	25.0	11
13	X	30.0	12

259.2×10^{-6}

$1/\lambda = 0.00386 \times 10^{6}$

= MTBF = 3860 hours

2.7.2 Fault Code Establishment

If the information along each interdependency line is sensed, the failure of any LRU will produce a fault-code pattern. This pattern can be used to isolate the fault. In the foregoing example, if a "1" indicates no fault and a "0" indicates a fault, the code will be:

	Sensor No.																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
LRU Failed																		
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0
5	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
6	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
7	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
8	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
9	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
10	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
No Fault	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

It can be noted from the above pattern that only those sensors that contribute to the uniqueness of the fault pattern need be used. Thus, it can be seen that sensors 2 and 3 and 7 and 8 could be removed without sacrificing the uniqueness of the words. Also, sensors 13, 14, and 15 will all fault together, since LRU's 9 and 10 are connected in a loop. Thus, any two of these (such as 13 and 14) can be omitted since they supply no additional information. It is evident that a fault in LRU 9 cannot be discerned from a fault in LRU 10 by the sensor outputs. The redundant sensors can be omitted only if the LRU that has multiple outputs will lose all of its outputs when it fails. If this is not certain to occur, then the sensors should be chosen on the basis of the probabilities of failure.

2.7.3 Interdependency Establishment

In the example, the table of failure rates shows that the outputs of LRU 2 are all equally likely to fail. A channel splitter (LRU 2) usually accepts a common input and then branches into several identical and independent channels. This means that each output could fail without affecting the others. In this case, monitoring one of the outputs would not assure the status of the others. The three synchronizer outputs, however, would not be independent. All would be derived from a common clock that would be counted down to the PRF frequency. All would have the same repetition rate so that all would depend on the complete counter working properly. If the relative complexities of the circuits needed to generate the outputs are as shown in DN 2.7.3 (1), the probability of separate or related failures of the three outputs can be calculated based on these relative complexities. The probability of detecting an LRU failure by monitoring only output 1 expresses the dependency relationship that output 1 has with the rest of the LRU. This probability is:

$$D_1 = \frac{\text{no. of common elements}}{\text{total no. of elements}}$$

or

$$\frac{48}{48 + 4} = 92.2 \text{ percent}$$

This means that 92.2 percent of the times that output 1 fails, the other outputs will be missing also. The other two outputs will have dependencies:

$$D_2 = \frac{48}{48 + 6} = 89 \text{ percent}$$

and

$$D_3 = \frac{48}{48 + 8} = 86 \text{ percent}$$

In general this dependency can be calculated for any output with respect to any other output by the formula:

$$D = \frac{\lambda c}{\lambda c + \lambda s}$$

where

D is the dependency factor

λc is the failure rate of the common elements between the outputs in question

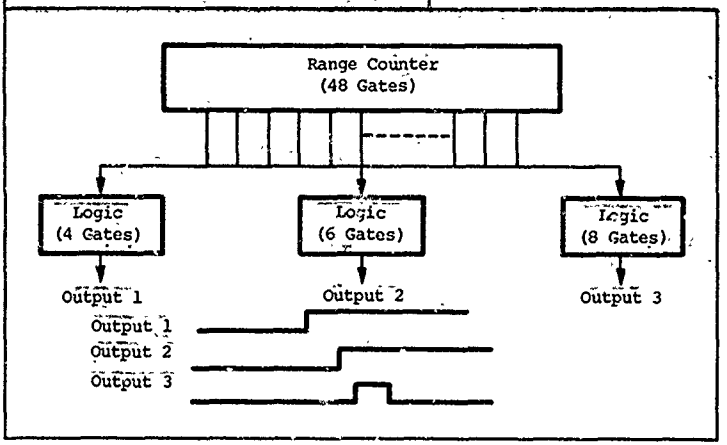
λs is the failure rate of those portions of the LUR peculiar to the output for which D is being calculated.

In the example, the failure rates (λ's) are considered to be proportional to the number of circuits in each branch, assuming that the type of logic is identical throughout. Also in the example, the dependency of any output is the same for either of the remaining two outputs.

A system can be completely described by listing the outputs, the failure rates, and the output dependencies for each LRU. Thus, the example case is:

Output Number	LRU Number	Output Goes to LRU Number	Failure Rate x 10^{-6}	Number of Dependencies
1	1	2	13.1	0
2	2	3	4.3	0
3	2	4	4.3	0
4	2	7	4.3	0
5	3	5	10.1	0
6	4	6	12.6	0
7	5	4	16.7	2
8	5	6	18.0	2
9	5	7	21.3	2
10	6	7	15.3	0
11	7	8	12.0	0
12	8	9	25.2	0
13	9	10	11.3	1
14	9	11	11.3	1
15	10	9	15.6	0
16	11	12	20.1	0
17	12	13	25.0	0
18	13	14	30.0	0

SUB-NOTE 2.7.3 (1) Example Synchronizer



And the dependencies are:

Output Number	Percent	On Output Number
7	92.2	8
7	92.2	9
8	89	7
8	89	9
9	86	7
9	86	8
13	100	14
14	100	13

The dependency connotations are given for each output that has a dependent association with another output. Three types of multiple output situations are illustrated. LRU 2 has three outputs with a zero dependency; i.e., each output is completely independent of the others. LRU 5 has three dependent outputs. For instance, output 7 has a 92.2 percent dependency with output 8. This means that 92.2 percent of the time that output 7 is missing because of a failure of LRU 5, output 8 will be missing also. LRU 9 has two outputs which are completely dependent; i.e., they are taken from the same point internal to the LRU. This is a 100 percent dependency, for whenever one output is missing, the other is certain to be missing also.

2.7.4 Evaluation of a Particular Sensor

With the above information, the usefulness of placing a sensor at any particular point in the system can be calculated on the basis of the uniqueness of the fault pattern produced by a given set of sensors and by the probability that a given fault will occur. In general, the more faults that a given sensor system can isolate (particularly on the first attempt), the better the system is. In selecting the optimum placement of sensors, a quantitative measurement of the system capability to isolate faults is required. If the fault code pattern produced by a sensor set for a given fault is unique, then that fault will be isolated on the first attempt. If a particular fault does not produce a unique fault code pattern, the fault cannot be isolated with certainty on the first attempt. However, if the fault is isolated to two possible LRU's,

the repair can be made on the second substitution. This is not as desirable as immediate isolation, but is assuredly more desirable than isolating the fault on three or greater attempts. Another factor in assessing the value of a given set of sensors would be whether or not a set isolates the most frequent faults. Thus, those sensors isolating frequent faults are more desirable than those isolating faults that occur less often. Given the time that the equipment is to operate and the failure rate of the LRU's, the probability of a fault in a particular LRU during the mission time can be found by:

$$P = 1 - e^{-\lambda T}$$

where

P is the probability of failure,

λ is the failure rate per 10^6 hours of the LRU

T is the mission time.

2.7.5 Evaluation of a Sensor Set

A sensor set evaluation coefficient can be calculated by:

$$SE = \frac{P_1}{P} + \frac{1}{2}\,\frac{P_2}{P} + \cdots \frac{1}{n}\,\frac{P_n}{P}$$

where

SE is the sensor evaluation factor

P_1 is the probability of the failures isolated on the first substitution; i.e., those failures uniquely specified by the fault code

P_2 is the probability of the failures isolated after two substitutions; i.e., those failures isolated to pairs by the fault code

P_n is the probability of the failures isolated after n substitutions; i.e., those failures isolated to groups of n by the fault code, and

P is the probability of any failure.

The 1/n coefficients give less and less weight to later substitutions although the effect of adding an additional substitution decreases as n gets larger. (The weighting changes greatly when going from one to two substitutions, but less so when going from 10 to 11.)

The question of dependent outputs can be handled by considering the following simple case. Consider, for example, an LRU with a simple resistive network having three dependent outputs, each seeing an infinite load impedance. Assuming that all the resistors are identical and have equal dissipations, the failure rates will be the same. The output dependency relationships can be calculated from the relative complexities of the parts. Whenever output A fails, there is a 50/50 chance that R1 has failed. This means that 50 percent of the time, outputs B and C will be missing also. Therefore, the dependency with A can be expressed by:

Output	Dependency With	Output
A	50%	B
A	50%	C

B is identically the same type of output as A, and therefore:

Output	Dependency With	Output
B	50%	A
B	50%	C

When output C fails, there is a 1/5 chance that the failure will be due to R1, causing A and B to be missing also. Therefore:

Output	Dependency With	Output
C	20%	A
C	20%	B

If all three outputs are not sensed (for instance, if only A is sensed), the percentage of isolated failures to the total possible failures can be calculated in the form of the sensor evaluation coefficient as:

$$SE_A = \frac{P_A}{P} = \frac{P_{R1} + P_{R2}}{P_{R1} + P_{R2} + P_{R3} \ldots + P_{R7}}$$

Assuming that the failure rates per resistor are all equal to one, this reduces to:

$$SE_A = 2/7$$

Similarly,

$$SE_B = 2/7$$
$$SE_C = 4/7$$

The outputs, failure probabilities, and sensor evaluation coefficients (SEC) can be summarized as follows:

Output	Failure Probability (P)	Dependency (D)	On Output	SEC
A	2	50%	B	2/7
A	2	50%	C	2/7
B	2	50%	A	2/7
B	2	50%	C	2/7
C	5	20%	A	4/7
C	5	20%	B	4/7

A generalized formula for the sensor evaluation coefficient for the first substitution only is as follows:

For a sensor at A only

$$SE_A = \frac{P_A}{P_A + (P_B - D_B P_B) + (P_C - D_C P_C)} = \frac{2}{2 + (2-1) + (5-1)} = \frac{2}{7}$$

For sensors at A and C:

$$SE = \frac{P_A + P_C - P_C D_C}{P_A + P_B + P_C - P_B D_B - P_C D_C} = \frac{2 + 5 - 1}{2 + 2 + 5 - 1 - 1} = \frac{6}{7}$$

This can be seen to be correct, for sensors at A and C will isolate 6/7 of the total possible failures. In general, then, the sensor evaluation coefficient can be found from the quotient of the summation of the failure probabilities of all unique fault code failures by the summation of all failures, in each case subtracting out a single dependency product wherever two dependent inputs appear (either numerator or denominator).

The total merit of any set of sensors can be evaluated by calculating a sensor evaluation coefficient for a set of sensors and comparing it with the coefficient for other sets. The higher the coefficient, the better is the sensor set. Also, the relative effectiveness of any particular ISTS system can be ascertained by comparing its sensor evaluation coefficient to the sensor evaluation coefficients of other systems.

2.8 Analog Sensors

The sensor designs described below can be used individually or in combination as "building blocks" to form a variety of sensors.

a. Envelope Detector

The circuit shown in section A of SN 2.8 (1) is an active envelope or video detector useful for RF signals from 5 to 50 MHz. By properly selecting ratios of R_1 and R_5, the gain can be selected anywhere between 0 and 26 dB. The envelope rise and fall times are less than 1 microsecond so that the circuit is useful for detection of video pulses equal to or greater than 1 microsecond.

This sensor design can be scaled for operation below 5 MHz by increasing the values of the capacitors in inverse proportion to the scaled frequency ratio. For example, if a video detector is required for a 500 KHz signal, all four capacitor values are increased by a factor of 10 (the ratio of 5 MHz to 500 KHz). It should also be recognized that the detector rise and fall times increase proportionally so that, in the above example, the circuit will detect video pulses of 10 microseconds or greater.

The detector design utilizes a buffer amplifier (Q1) to prevent loading of the test point. This stage is an inverting amplifier whose gain, G, is

$$G = \frac{R_1}{R_2}$$

for all reasonable transistor betas. Sensor gain can be selected by varying R_1 while leaving R_5 at its nominal value. The collector of Q1 is AC coupled to a conventional diode detector. The output stage is an emitter follower to limit the loading of the detector and to provide a low impedance drive signal to the evaluator.

b. Gated Video Buffer

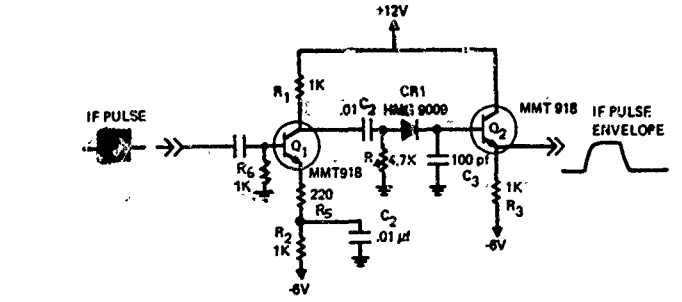
The circuit shown in section B of SN 2.8 (1) is a gated video buffer for general use as a linear amplifier with an optional gating input. When the gating function is used, the amplifier output is zero except during an "enable" signal, when the sensor performs normally. To eliminate the gating function, the gate input terminal is left open and the circuit is continually enabled. The sensor is gated off by grounding the cathode of CR2, which shunts out the input signal and maintains the sensor output at zero.

Sensor gain can be adjusted over a range of approximately 30 dB by altering the ratio of R_6/R_8. The gain equation is

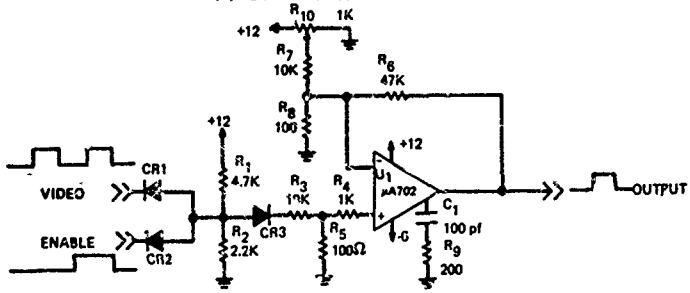
$$G = 1 + \frac{\left(\frac{R_6}{R_8}\right)\left(\frac{R_5}{R_3}\right)}{}$$

Where R_3-R_5 form an input attenuator and R_6-R_8 provide amplification. The purpose of the input attenuator is to isolate the test point in the event of sensor failure. Adjustment R_{10} provides a means of compensating the effects of bias current through R_1 and CR_3. The use of this bias circuit results in a linear amplifier even though the signals are injected through a diode gate.

SUB-NOTE 2.8.1 (1) Analog Signal Amplitude Sensors

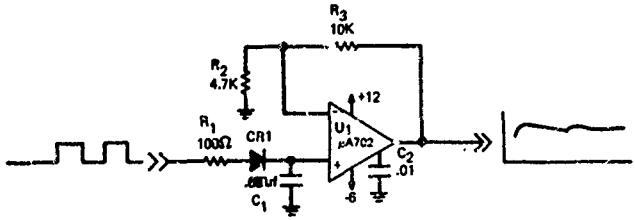


(A) ENVELOPE DETECTOR



NOTE: ALL DIODES HMG 9009

(B) GATED VIDEO BUFFER



(C) VIDEO DETECTOR

A compensation network R_9-C_1 is provided to make the 702 operational amplifier unconditionally stable. These values can be adjusted in specific applications by using the guidelines provided in application notes and specification sheets for 702 operational amplifiers.

c. Video Detector

The circuit shown in section C SN 2.8 (1) is a general-purpose video detector. The circuit can be used as a peak detector for sinusoidal signals, square waves, pulse trains, etc. The detector discharge time is approximately 10 milliseconds so that repetitive signals as low as 1 KHz will be detected and the DC output of the sensor will be directly proportional to the amplitude of the input signal. The upper frequency limitation is approximately 1 MHz.

The circuit functions for input signals ranging from 1 to 4 volts. Circuit gain can be selected by adjusting the ratio of R_2 and R_3 in accordance with the following:

$$\text{Gain} = 1 + \frac{R_3}{R_2}$$

The circuit becomes a negative peak detector simply by reversing diode CR_1 but the gain equation is unchanged.

This circuit is compensated conservatively by C_2 for general-purpose applications. The operacional amplifier is simply a buffer for the already detected signal so that there is no need for frequency response beyond approximately 1 KHz.

CHAPTER 3

MAINTAINABILITY PROGRAM PLAN

This chapter contains a detailed task description of a Maintainability Program Plan with guidelines, methodology, documentation requirements, and an example of the plan for the Multiplexer Set.

CHAPTER 3 MAINTAINABILITY PROGRAM PLAN

SECTION 3A - DETAILED TASK DESCRIPTION

Design Note 3A1 - Purpose of Maintainability Program Plan

SECTION 3B - GUIDELINES AND METHODOLOGY

Design Note 3B1 - Discussion of Detailed Requirements of MIL-STD-470

SECTION 3C - DOCUMENTATION REQUIREMENTS

Design Note 3C1 - Data Item Description

SECTION 3D - MULTIPLEXER SET MAINTAINABILITY PROGRAM PLAN EXAMPLE

Design Note 3D1 - Multiplexer Set Contractor Organization and Management

3D2 - Multiplexer Set Maintainability Program Plan Tasks

3D3 - Multiplexer Set Reviews, Reports, Milestones, and Cross-Index

SECTION 3A

DETAILED TASK DESCRIPTION

This section describes the purpose and applicability of the maintainability program plan.

SECTION 3A DETAILED TASK DESCRIPTION

DESIGN NOTE 3A1 - PURPOSE OF MAINTAINABILITY PROGRAM PLAN

1. GENERAL

1(1) Maintainability (M) Program Plan Task Checklist

1(2) Contents of Maintainability Program Plan

2. APPLICABILITY

DESIGN NOTE 3A1 PURPOSE OF MAINTAINABILITY PROGRAM PLAN

1. GENERAL

The purpose of the maintainability program plan is to ensure that a system or equipment will be designed to meet the specified maintainability requirements in an effective, timely, and economical manner. It provides for a systematic analysis of the maintainability effort and gives guidelines for meeting or exceeding the specified requirement. To be effective, the maintainability program must be integrated with the system/equipment design engineering program to assure effective, timely, and economical accomplishment. The program should be consistent with the type and complexity of systems or equipment and phase of the acquisition and shall ensure attainment of the contractual maintainability requirements. The essential tasks that the program plan should address are shown in SN 1 (1) and are discussed individually in Chapters 3 through 17. The maintainability program plan contents are shown in SN 1 (2). An example of a maintainability program plan is included in Section 3D.

SUB-NOTE 1(1) Maintainability (M) Program Plan Task Checklist

- M Program Plan
- Design Review
- M Allocations
- M Reports
- Trade-Offs
- Special M Analysis
- M Model
- Maintenance Concept
- GFE Integration
- M Design Criteria and Specification Inputs
- M Predictions
- M Design Audit
- M Demonstration Plan
- M Demonstration-Conduct and Report
- M Data Collection Analysis and Corrective Actions

SUB-NOTE 1(2) Contents of Maintainability Program Plan

- Work to be accomplished under each task
- Time phasing of each task
- Contractor organizational element responsible for implementing the maintainability program
- Lines of communication between the contractor organization responsible for implementing the maintainability program and other contractor interfacing organizations
- Appropriate customer-contractor program milestone review points
- Specific technique(s) for allocating quantitative requirements to lower level functional elements of the system (group, unit, assembly, subassembly, etc.)
- Specific technique(s) for maintainability predictions of quantitative requirements at lower level functional elements of the system
- The general approach to be used in modeling the system or equipment.
- Interfaces between the maintainability program and other closely related programs (logistics, reliability, safety engineering, etc.)

2. APPLICABILITY

The requirements for a maintainability program plan apply to the development of all systems and equipment subject to validation. When validation is not involved, the extent of a maintainability program plan's applicability should be specified in the Request for Proposal or Contract Work Statement, or both.

SECTION 3B

GUIDELINES AND METHODOLOGY

This section describes the guidelines and methodology for preparing a maintainability program plan by discussion of detailed requirements of MIL-STD-470.

SECTION 3B GUIDELINES AND METHODOLOGY

DESIGN NOTE 3B1 - DISCUSSION OF DETAILED REQUIREMENTS OF MIL-STD-470

1. BACKGROUND

2. PREPARE THE MAINTAINABILITY PROGRAM PLAN

DESIGN NOTE 3B1

DISCUSSION OF DETAILED REQUIREMENTS OF MIL-STD-470

1. BACKGROUND

MIL-STD-470 sets forth the requirements for conducting a maintainability program. The program requirements of this standard are discussed in the following paragraphs.

2. PREPARE THE MAINTAINABILITY PROGRAM PLAN

In response to a Request for Proposal (RFP), the contractor will describe, in as much detail as appropriate, how he plans to conduct the maintainability program. He will discuss how he intends to accomplish all of the applicable and essential tasks of the program shown in SN 1(1) of DN 3A1, plus the pertinent information shown in SN 1(2) of DN 3A1. When there is a contractor's proposal for the Validation Phase, normally a preliminary maintainability program plan will be submitted to the procuring activity. The contractor will then be expected to expand and modify the preliminary plan as necessary during the Validation Phase to produce the proposed maintainability program plan that will guide the maintainability program during the Full-Scale Development Phase. Since the maintainability program plan describes how the contractor intends to satisfy mission maintainability requirements, the plan is a factor in source selection.

The maintainability program must be consistent with the type and complexity of the system or equipment and be integrated with the entire design engineering effort. The maintainability program plan provides the contractor with a means for showing how he expects to tailor the maintainability program to meet these requirements in an effective, timely, and economical manner. In describing the planned interfaces between the maintainability program and other closely related programs or efforts listed in the standard, there need be only enough information to show that duplication of effort will be avoided and continuity

between interrelated functional responsibilities, irrespective of organizational boundaries, is assured. The standard is flexible with regard to what portions of the plan become part of a full-scale development contract. The plan may be contracted for in whole or in part, depending upon mutual agreement between the contractor and the procuring agency. It is important to assure that necessary basic tasks are properly interpreted and mutually understood, to give the procuring activity confidence that maintainability requirements will be met at the end of the Full-Scale Development Phase. At the same time, this gives the contractor the flexibility he needs to avoid the necessity for formal changes in the future.

SECTION 3C

DOCUMENTATION REQUIREMENTS

This section describes the documentation requirements which may be called for in an RFP. It includes the data item.

SECTION 3C DOCUMENTATION REQUIREMENTS

DESIGN NOTE 3C1 - DATA ITEM DESCRIPTION

1. GENERAL

DESIGN NOTE 3C1 DATA ITEM DESCRIPTIONS

1. GENERAL

The data item for the maintainability program plan is contained in SN 1(1). This is the data item that would be listed on Contract Form DD-1423, where one is called out, for a maintainability program plan.

SUB-NOTE 1 (1) (Sheet 1 of 2 sheets) Data Item Description

DATA ITEM DESCRIPTION

2. IDENTIFICATION NO(S)	
AGENCY	NUMBER
USAF	DI-R-3533/ R-101-2

1. TITLE

Reliability/Maintainability Program Plan

3. DESCRIPTION/PURPOSE

This Plan is used by the procuring activity (1) to evaluate the contractor's planning for his Reliability/Maintainability Program, (2) to review and approve the contractor's planned Reliability/Maintainability Program, and (3) to monitor and evaluate the contractor's conduct of his Reliability/ Maintainability Program.

4. APPROVAL DATE

21 May 1971

5. OFFICE OF PRIMARY RESPONSIBILITY

AFSC

6. DDC REQUIRED

8. APPROVAL LIMITATION

7. APPLICATION/INTERRELATIONSHIP

This Data Item Description is applicable to systems development contracts during contract validation, full scale development and production phases and equipment development/procurement contracts when contractors are required to conduct a Reliability/Maintainability Program. This plan may be obtained either precontractually, during the RFP/IFB phase, or as a product of the validation phase. When a prior reliability program plan has been proposed and approved by the procuring activity, the specific requirements of this Data Item Description may be satisfied by supplementing the prior plan.

9. REFERENCES (Mandatory as cited in block 10)

MIL-STD-470
MIL-STD-471
MIL-STD-721
MIL-STD-785

MCSL NUMBER(S)

10. PREPARATION INSTRUCTIONS

1. The Reliability/Maintainability Program Plan contains the plans for the accomplishment of each Reliability/Maintainability Program task specified by the contract. The plan will provide a cross-index, in accordance with the following outline, which shows the relationships between program tasks and (1) applicable specifications or standards cited by the contract work statement, (2) other reference documents, and (3) contractor policies and standards:

Format for Program Plan Cross-Index

Ref Para of MIL-STD-785 and/or MIL-STD-470	Applicable Task or Para No of Program Plan	Other Reference Documents	Company Policies, Procedures & Controls	Estimated Manloading for 1st ____ Months

2. The plan shall also identify and define the following as a minimum:

a. The work to be accomplished for each applicable task delineated in MIL-STD-785 and MIL-STD-470.

b. The time phasing and manloading involved.

c. The contractor organizational element assigned responsibility and authority for implementing the Reliability/Maintainability Program.

d. Lines of communication between the contractor organizational element responsible for implementing the program and other contractor interfacing organizational elements.

e. Appropriate customer-contractor program milestone review points.

f. Method of control over subcontractor and vendor reliability/maintainability programs.

DD FORM 1664

SUB-NOTE 1 (1) (Sheet 2 of 2 sheets) Data Item Description

DI-R-3533/R-101-2 (Continued)
10. Preparation Instructions (Cont).

g. The purpose and expected results of each task and the planned methods for monitoring, assessing, reporting, and taking appropriate action regarding the status, accomplishments, and problems.

h. Specific techniques for allocating quantitative requirements to lower level functional elements of the system (subsystem, assembly, or components).

i. Specific techniques for making reliability/maintainability predictions.

j. Proposed methods for demonstrating the achievement of quantitative reliability/maintainability requirements.

3. The plan shall identify and define interfaces between the Reliability/Maintainability Program and the following closely related programs or elements:

a. Logistics support evaluations.

b. Personnel Subsystem Program.

c. Systems engineering.

d. Systems/cost effectiveness analysis.

e. System life-cycle cost analysis.

f. Design engineering.

g. Value engineering.

h. Data collection and analysis procedures.

SECTION 3D

MULTIPLEXER SET MAINTAINABILITY PROGRAM PLAN EXAMPLE

This section contains an example of a maintainability program plan for the Multiplexer Set.

SECTION 3D MULTIPLEXER SET MAINTAINABILITY PROGRAM PLAN EXAMPLE

DESIGN NOTE 3D1 - MULTIPLEXER SET CONTRACTOR ORGANIZATION AND MANAGEMENT

1. ORGANIZATION AND MANAGEMENT

1 (1) Reliability and Maintainability Organization

1 (2) The Contractor's Functional Organization

2. PROGRAM CONTROLS

DESIGN NOTE 3D2 - MULTIPLEXER SET MAINTAINABILITY PROGRAM PLAN TASKS

1. GENERAL
2. ANALYSIS
3. MAINTENANCE CONCEPT AND PLAN INPUTS
4. MAINTAINABILITY DESIGN CRITERIA
5. DESIGN TRADE-OFFS
6. MAINTENANCE TIME PREDICTIONS
7. SUBCONTRACTOR AND VENDOR MAINTAINABILITY CONTROL
8. INTEGRATION WITH GOVERNMENT OR ASSOCIATE CONTRACTOR ITEMS
9. DESIGN REVIEWS
10. DATA COLLECTION, ANALYSIS, AND CORRECTIVE ACTION
11. MAINTAINABILITY DEMONSTRATION
12. MAINTAINABILITY PROGRAM STATUS REPORT
13. PROJECTED MAINTAINABILITY PROGRAM

DESIGN NOTE 3D3 - MULTIPLEXER SET REVIEWS, REPORTS, MILESTONES, AND CROSS-INDEX

1. PROGRAM REVIEWS AND REPORTS

1 (1) Maintainability Program Reports

2. PROGRAM MILESTONES

2 (2) Multiplexer Set Maintainability Milestones

3. SPECIFICATION/PLAN CROSS-INDEX

3 (1) Maintainability Specification/Plan Cross-Index

DESIGN NOTE 3D1 MULTIPLEXER SET CONTRACTOR ORGANIZATION AND MANAGEMENT

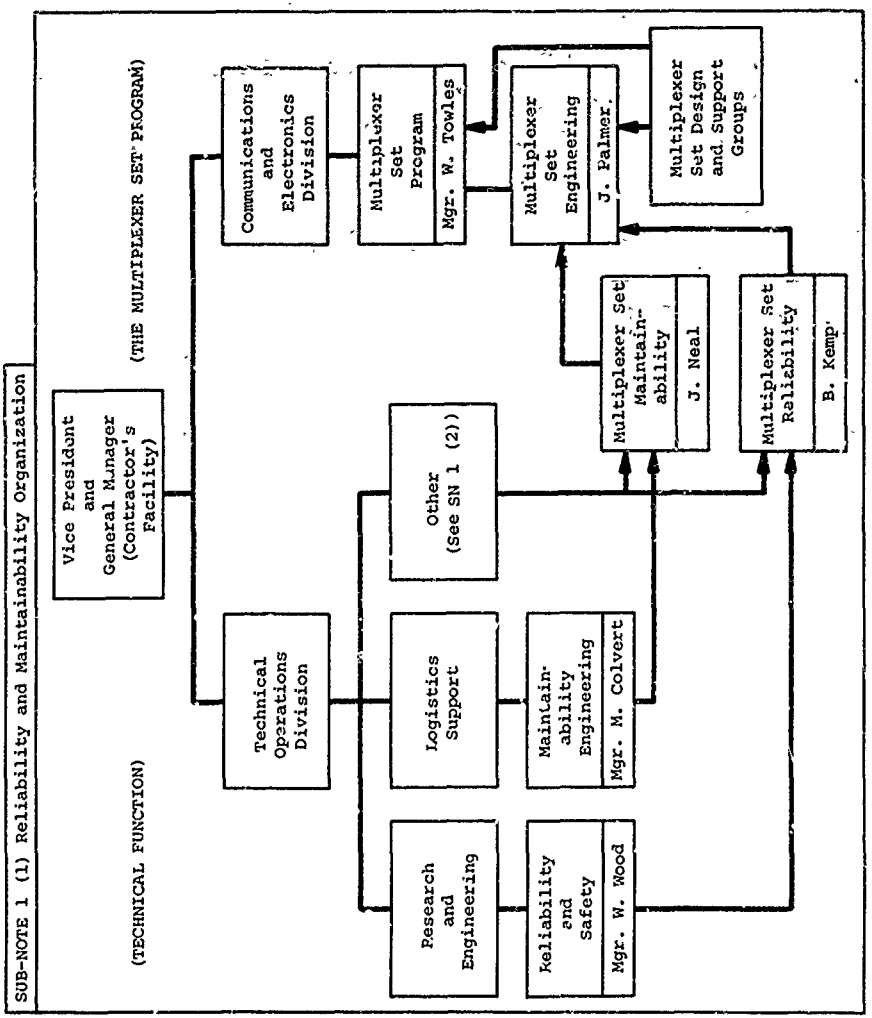
1. ORGANIZATION AND MANAGEMENT

Reliability and maintainability responsibility at the contractor's facility is chartered to the Vice President of Technical Operations. The structure of the organization and its relationship to the Multiplexer Set Project is shown in SN 1(1). The key personnel responsible for the Multiplexer Set reliability and maintainability are identified by name in SN 1(1).

Maintainability program application at the contractor's facility is the responsibility of the Logistics Division. The Logistics Division is comprised of four operating departments, each separated into project and functional staff support elements. These departments include Logistics Engineering, Technical Publications, Training and Field Service, and Supply Support. A Logistics Manager, assigned to the Multiplexer Set project, directs the activities of these departments in fulfillment of contractual logistics requirements. In support of the Multiplexer Set Logistics Manager, functional managers for each of the logistical disciplines assign technically qualified personnel and provide staff support in the form of technical research and consultation.

Application of maintainability and maintenance engineering programs is the specific responsibility of the Multiplexer Set Logistics Engineering organization. Integration of these closely related areas provides appropriate continuity of maintainability and maintenance analysis, planning, and documentation, starting with predesign study and continuing through successful completion of system acceptance testing. Logistics Engineering also acts as a technical coordinating and review element for other logistics organizations, such as Publications and Spares Support which become most active in latter design phases.

Personnel in all applicable disciplines are assigned to the Multiplexer Set. These specialists form a project team, with both formal and informal working


SUB-NOTE 1 (1) Reliability and Maintainability Organization
(TECHNICAL FUNCTION)
Vice President and General Manager (Contractor's Facility)
(THE MULTIPLEXER SET PROGRAM)
Communications and Electronics Division
Multiplexer Set Program
Mgr. W. Towles
Multiplexer Set Engineering
J. Palmer
Multiplexer Set Design and Support Groups
Technical Operations Division
Logistics Support
Other (See SN 1 (2))
Multiplexer Set Maintain-ability
J. Neal
Multiplexer Set Reliability
B. Kemp
Maintain-ability Engineering
Mgr. M. Colvert
Research and Engineering
Reliability and Safety
Mgr. W. Wood

interfaces. Formal lines of communication between reliability, maintainability, and related disciplines are maintained at the manager level, while day-to-day informal interfaces are established between project team members at all levels. All Multiplexer Set personnel work in the same area and are in constant contact with each other.

The relationship of reliability and maintainability to other related company organizations and functions is shown in SN 1(2). All pertinent organizations are within the Technical Operations Division.

2. PROGRAM CONTROLS

The maintainability program will be controlled through formally scheduled program reviews, detailed task schedules, and review of program reports. These subjects are presented in detail in DN 3D2 and DN 3D3.

The technical specialists assigned to the Multiplexer Set program are responsible for assuring that each task is completed in a competent, timely, and accurate manner. Each task is individually scheduled by project programming. Complete Multiplexer Set program schedules are issued to all program task leaders, including the reliability and maintainability specialists. Weekly program review meetings are held, during which the progress of each scheduled item is reported to the program management. The program schedules are revised and reissued as appropriate. In this manner, tasks are assured of being completed on schedule and problem areas are brought to management attention and are resolved in a timely manner. When a scheduled task is completed, the completion date is recorded in the program schedule and the schedule becomes a record of the accomplished tasks.

SUB-NOTE 1 (2) The Contractor's Functional Organization
Vice President and General Manager (The Contractor's Facility)
Technical Operations Division
Research and Engineering
Reliability Engineering
Human Engineering
Components Engineering
Safety
Design Engineering
System Engineering
Value Engineering
Mechanical Laboratories
Quality
Quality Assurance
Data Collection
and
Analysis
Logistics
Maintainability Engineering
Personnel Subsystem
Training and Field Service
Technical Publications
Supply Support
Maintenance Engineering

DESIGN NOTE 3D2 MULTIPLEXER SET MAINTAINABILITY PROGRAM PLAN TASKS

1. GENERAL

This Design Note contains the maintainability program plan for the Multiplexer Set and ancillary equipments. Format is consistent with the requirements of AFSCM/AFLCM 310-1, Data Item R-101-2. The specific tasks to be accomplished during application of the Multiplexer Set maintainability program are addressed in subsequent paragraphs.

2. ANALYSIS

An analysis of the maintainability requirements established by the contract and Specifications RADC 5265 and 5266 will be accomplished. Based on the results of this analysis, detailed maintainability constraints will be defined for inclusion in Part I Configuration Item (CI) specifications for the Multiplexer Set ancillary rate conversion equipments.

These constraints will be in both qualitative and quantitative dimensions, with quantitative constraints being suitable for demonstration in accordance with MIL-STD-471, Method 2.

The quantitative requirements associated with the Multiplexer Set and ancillary rate conversion equipments are as follows:

a. Mean corrective maintenance time ($\bar{M}_{ct}$): 12.0 minutes
b. Maximum corrective maintenance time (95th percentile) ($M_{max\ ct}$): 36.0 minutes

These requirements will be allocated to the multiplexer and demultiplexer level, using two forms of data:

a. An estimate of the average maintenance time expected for one equipment relative to another.
b. An estimate or apportionment of the failure rate distribution among the equipments when configured as a system or set.

Neither of the above need be known in terms of real values such as minutes of downtime or failures per hour. Relative maintenance time is estimated in terms of a value x, and estimated failure rate in terms of failure percentage associated with each equipment. The following example illustrates the allocation technique to be used:

EXAMPLE

Assume a system comprised of two equipments which, in combination, must demonstrate a mean corrective maintenance time ($\overline{M}_{ct}$) of 12.0 minutes. Let an estimate of the $\overline{M}_{ct}$ associated with one equipment equal a value X. Further assume that due to complexity, type, or other factors, the estimated $\overline{M}_{ct}$ of the second equipment relative to the first is one and one half times that of the first (1.5x).

When the two equipments are configured as a set, let the first be expected to contribute 75 percent of the total failures, with the second contributing the remainder.

That portion of the allowed 12.0 minutes system $\overline{M}_{ct}$ to be allocated to each equipment can then be established by solving the following equation for x.

$$(x)\ (0.75) + (1.5x)\ (0.25) = 12.0 \text{ minutes}$$

$$1.125\ x = 12.0$$

$$x = 10.67 \text{ minutes}$$

Hence, the allocated $\overline{M}_{ct}$ for the first equipment is x or 10.67 minutes and for the second is 1.5 x or 16.01 minutes.

Allocation of the $M_{max\ ct}$ requirement will maintain the 3:1 (36.0:12.0) ratio associated with the specified mean and maximum downtime requirements. Thus, should the allocated mean downtime for one of the equipments comprising the multiplexer set be 10.0 minutes, the allocated maximum downtime for that equipment would be (3) (10) or 30.0 minutes.

Based upon input data such as operational and support concepts, the maintainability analysis will also translate environmental, facility, personnel and other support-related requirements into detailed qualitative and quantitative maintainability constraints.

In addition to the evaluation and assignment of qualitative and quantitative constraints, the maintainability analysis effort will include:

a. Assessment of design details in support of prediction preparation.

b. Evaluation of design alternates in terms of their respective maintainability impact.

c. Selection of maintainability demonstration task samples and reduction of observed data.

Analysis findings will be incorporated in the Reliability and Maintainability Allocations, Assessments, and Analysis Report.

3. MAINTENANCE CONCEPT AND PLAN INPUTS

Consistent with the maintenance philosophy, maintenance planning inputs will be provided for use in development of the training analysis, spare parts selection, and preparation of technical manuals. This effort will address organizational and field maintenance levels, identification of required types and quantities of support equipments, and frequency and type of required maintenance tasks.

The quantities and types of skills required will be addressed as a part of the training analysis.

It is assumed that the Multiplexer Set equipments will be located at Government installations having existing maintenance support facilities. Therefore, facility requirements for the Multiplexer Set will be defined in terms of recommended work area size and support equipment power requirements only.

Maintenance planning information will be formally documented in the form of the Aerospace Ground Equipment (AGE) Plan, AGE Recommendation Data (AGERD), and the Calibration Requirements Summary (CRS).

4. MAINTAINABILITY DESIGN CRITERIA

Based upon results of the continuing maintainability analysis effort, detailed maintainability design criteria will be provided to the Multiplexer Set design organizations.

Where appropriate, criteria application techniques and procedures will also be provided by the Multiplexer Set maintainability organization.

Following the initial allocation and specification effort, maintainability audit and analysis will continue throughout the development and testing interval. Such effort provides a basis for assessment of the evolving design in terms of specified maintainability constraints and recognized maintainability design principles. Where analysis findings indicate the deviation or potential deviation of ultimate design performance from such acceptable limitations, supplemental design guidance will be initiated by the program maintainability organization. This guidance will take two basic forms: personal liaison and coordination between design and maintainability personnel, and guidance documentation to responsible program management. The latter form will be used where the former does not yield acceptable design alteration. The contractor's data collection system will include a separate file of such documented guidance. This coordination and documentation effort, based upon results of the repetitive maintainability audit and analysis, represents the generation of design criteria and guidance supplemental to that contained in the end item specifications.

5. DESIGN TRADE-OFFS

A trade study will be performed for purposes of defining the most cost effective disposition mode for printed circuit cards and modules comprising the Multiplexer Set. Alternates to be considered by this study are discard-at-failure (DAF) and repair of failed items at a depot or factory level facility.

The study will address all such items collectively rather than individually, and will be based upon deployment density and location information provided by the procuring activity.

Reference material contained in AFLCM/AFSCM 800-4, Optimum Repair Level Analysis, and RADC-TR-68-187, Maintainability of Micro Circuit Equipment will be used as a guide during study accomplishment.

The study format will be selected by the contractor, and study findings will be appropriately documented in a maintainability program status report.

Other trade-offs between candidate approaches to specific design requirements will occur frequently during the active design interval. By virtue of their quantity, and the expediency required for their completion, such trades will be largely conducted in an informal manner by means of personal contact and coordination.

When such trades involve packaging, fault isolation, or other areas having maintenance significance, maintainability will receive appropriate consideration in the selection process.

If analysis indicates that the selection process has yielded an unacceptable compromise to the Multiplexer Set maintainability performance, such findings will be addressed to responsible program management for resolution and will be suitably included in periodic maintainability status reports.

6. MAINTENANCE TIME PREDICTIONS

Maintenance time predictions will be prepared for the Multiplexer Set and ancillary rate conversion equipments. These predictions will be prepared in accordance with Method III of MIL-HDBK-472, or other methods approved by the procuring activity.

Predictions will be initially prepared early in the design phase and will be appropriately updated as design details become firm or are significantly modified by the design trade-off process.

Predicted maintenance time values will be included in periodic maintainability progress reports.

7. SUBCONTRACTOR AND VENDOR MAINTAINABILITY CONTROL

Vendor and/or subcontractor items comprising the proposed Multiplexer Set design are primarily of a piece part configuration and are combined into maintenance-significant items such as modules and printed circuit cards at the contractor's manufacturing facility.

However, acquisition of any maintenance-significant components will be accomplished, using appropriate specification and control of maintainability characteristics.

8. INTEGRATION WITH GOVERNMENT OR ASSOCIATE CONTRACTOR ITEMS

In the interest of establishing and maintaining an effective system support posture, interface of the Multiplexer Set equipments with existing equipments and facilities is of particular interest to the contractor's maintainability organization. Procuring activity information and recommendations in this area are considered both desirable and necessary.

Further, in the event Government or associate contractor items are integrated into the Multiplexer Set, impact of this move upon maintainability performance

will be analyzed, using item performance data supplied by the procuring activity. Any inconsistencies between maintainability performance of these items and the Multiplexer Set equipments supplied by the contractor will be identified and documented, with appropriate corrective recommendations, to the procuring activity for disposition.

9. DESIGN REVIEWS

Based upon requirements set forth by internal operating policies, review of engineering progress and status is made at appropriate stages in the Multiplexer Set development program. These internal reviews are augmented with formal preliminary and critical design reviews in which procuring activity representatives participate.

The contractor maintainability organization will be represented in all such reviews, assuring appropriate consideration of maintainability performance in the evolving design.

10. DATA COLLECTION, ANALYSIS, AND CORRECTIVE ACTION

During the Multiplexer Set maintainability program, a data collection, analysis, and corrective action system will be initiated and maintained.

The specified prediction technique outlines preferred data formats. Demonstration data will be documented in accordance with an approved plan yet to be developed. Therefore, this data system will serve primarily as a vehicle for documenting potential maintainability design deficiencies and the disposition status.

The format of the data system to be used will be selected by the contractor. When actual or potential maintainability design deficiencies are noted during the continuing design audit effort, they will be documented for analysis. Based on analysis findings, appropriate corrective recommendations and their

implementation status will also be recorded. This arrangement will provide a single coordinated source for data of this type.

11. MAINTAINABILITY DEMONSTRATION

Compliance of the Multiplexer Set, rate conversion equipment, and power supplies with the specified $\overline{M}_{ct}$ of 12.0 minutes and the specified $M_{max\ ct}$ of 36.0 minutes (95th percentile) will be formally demonstrated in accordance with MIL-STD-471 (Notice No. 1). Compliance of the Multiplexer Set equipment design with specified qualitative maintainability requirements will also be formally demonstrated by means of equipment inspection or testing, data analysis, or other methods as set forth in the quality assurance sections of applicable CEI specifications.

A demonstration will be conducted, using a contractor prepared maintainability demonstration plan approved by the procuring activity. Plan preparation will provide for demonstration in accordance with MIL-STD-471 (Notice No. 1), Test Method 2, with the consumer risk set at 10 percent. Demonstration planning, implementation, and documentation will be the responsibility of the Multiplexer Set maintainability organization. When appropriate, this organization may be assisted by the design and support elements associated with the Multiplexer Set program.

Contractor personnel will conduct the demonstration, using validated technical manuals and spares and support equipments consistent with the support concept defined during the system development interval. These personnel will match, as closely as possible, the skill level and experience expected of their Air Force operational maintenance counterparts.

The maintainability demonstration will be accomplished, using not more than two of the first eight Multiplexer Sets. Equipment configuration will be the same as that used for the reliability qualification test.

Preparation of the maintainability demonstration plan will be in accordance with DD-1423, Sequence Number B031. Not more than 45 days following completion of the maintainability demonstration, a maintainability demonstration report will be prepared and submitted in accordance with DD-1423 Sequence Number B035. This report will contain demonstration findings in accordance with MIL-STD-471 (Notice No. 1), paragraph 4.5. If demonstration findings provide the basis for a reject decision, the demonstration will be stopped and the procuring activity immediately notified. Appropriate corrective action will then be planned and implemented, and demonstration testing will be resumed or reinitiated.

12. MAINTAINABILITY PROGRAM STATUS REPORT

At quarterly intervals following submittal of the initial reliability and maintainability allocations, analysis, and assessments report (DD-1423, Sequence Number B027), a maintainability program status report will be submitted in accordance with DD-1423, Sequence number B033. This report will be combined with the reliability status report and will convey that information set forth in the data item as well as updated material initially submitted under DD-1423, Sequence Number B027.

13. PROJECTED MAINTAINABILITY PROGRAM

Maintainability efforts which are applicable once initial design, test, and production phases are complete are essentially twofold:

a. A continuing assessment of maintenance performance in the field environment.

b. Incorporation of modifications, as required, in a manner having acceptable impact upon overall equipment maintenance performance.

These efforts, while not provided under terms of the current contract, are typically provided in part by the developing contractor subject to separate negotiation.

DESIGN NOTE 3D3 — MULTIPLEXER SET REVIEWS, REPORTS, MILESTONES, AND CROSS-INDEX

1. PROGRAM REVIEWS AND REPORTS

Program reviews will be held in conjunction with the management and engineering presentations which are scheduled at 45-day intervals until the critical design review and at 90-day intervals thereafter. The subjects to be covered in these reviews include program status in relation to major milestones, design status, current problem areas, and proposed solutions. These periodic program reviews will serve as a planned, systematic audit of the programs at key milestones throughout the effort, and thus will ensure its integrity and adherence to system requirements. The maintainability specialists will normally present their respective technical data at these meetings.

Reports will be submitted in accordance with the contract data requirements list, Form DD-1423. The reports to be submitted are identified in SN 1(1).

2. PROGRAM MILESTONES

The milestones and related schedule for the maintainability program tasks described in this report are shown in SN 2(1). Program tasks are shown in relation to the major Multiplexer Set program milestones.

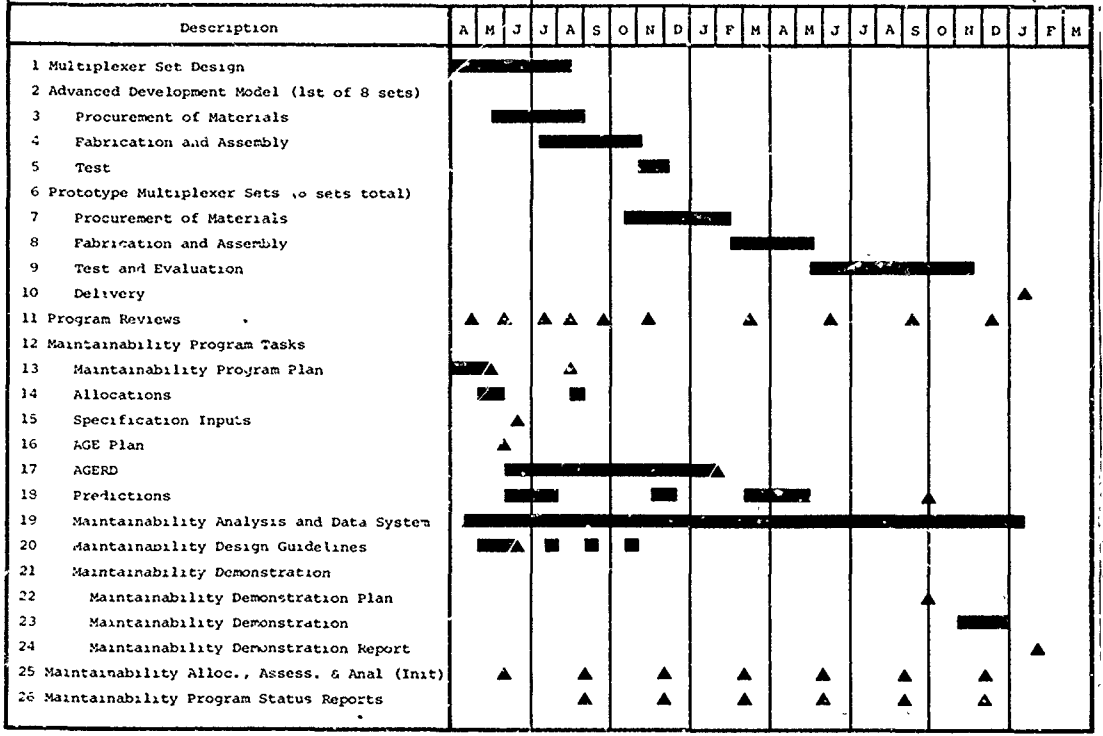
3. SPECIFICATION/PLAN CROSS-INDEX

A cross-index relating specifications and requirements for the maintainability program and the paragraph in which the requirement is discussed in this plan is shown in SN 3(1).

SUB-NOTE 1(1) Maintainability Program Reports

Item Number (CLIN)	Report	Applicable Data Item Description (Form DD-1664)	Comment
BC26	Maintainability Program Plan	R-101-2	Combined with reliability program plan
B031	Maintainability Demonstration	R-108-1	
3033	Maintainability Program Status Report	R-111-1	Initial issue will be separate document. Quarterly revisions will be included in reliability program status report (Item Number B027)
B035	Maintainability Demonstration Report	R-113-1	
B020	Aerospace Ground Equipment Plan	M-110	
B037	Aerospace Ground Equipment Recommendations	S-124	
B038	Calibration Requirements Summary	S-317	

SUB-NOTE 2 (1) Multiplexer Set Maintainability Milestones



SUB-NOTE 3 (1) (Sheet 1 of 2 sheets) Maintainability Specification/Plan Cross-Index

Reference Para of MIL-STD-470	Applicable Para of Program Plan	Reference Para of Data Description R-101-2	Task
4.1	3D1, 3D2, 3D3	1	Maintainability Program
5.1	3D1, 3D2, 3D3	1	Maintainability Program Plan
5.1.c	3D1 - 1.0	2c	Maintainability Organization
5.1.d	3D1 - 1.0	2d	Inter-Element Communication
5.1.e	3D3 - 2.0	2e	Milestone Review Points
5.1.f	3D2 - 2.0	2h	Allocation Techniques
5.1.g, 5.6	3D2 - 6.0	2i	Prediction Techniques
5.1.h	3D1 - 1.0	3	Interface with Related Efforts
5.2	3D2 - 2.0	2g	Maintainability Analysis
5.3	3D2 - 3.0	2g	Maintainability Concept Inputs
5.4	3D2 - 4.0	2g	Design Criteria
5.5	3D2 - 5.0	2g	Design Trade-Offs
5.7	3D2 - 7.0	2f	Vendor/Subcontractor Control
5.8	3D2 - 8.0	2g	Integration of Other Items

SUB-NOTE 3 (1) (Sheet 2 of 2 sheets) Maintainability Specification/Plan Cross-Index

Reference Para of MIL-STD-470	Applicable Para of Program Plan	Reference Para of Data Description R-101-2	Task
5.9	3D2 - 9.0	2e	Design Reviews
5.10	3D2 - 10.0	2g	Data Collection, Analysis, and Corrective Action
5.11	3D2 - 11.0	2j	Demonstration
5.12	3D2 - 12.0 3D3 - 1.0	2g	Status Reports

CHAPTER 4

DESIGN REVIEW

This chapter contains a detailed task description, guidelines, methodology, and procedures for design reviews from the maintainability viewpoint. It also has an example of a presentation for a design review and minutes of a design review meeting for the Multiplexer Set sample system.

CHAPTER 4 DESIGN REVIEW

SECTION 4A - DETAILED TASK DESCRIPTION

Design Note 4A1 - Design Review Structure

SECTION 4B - GUIDELINES AND METHODOLOGY

Design Note 4B1 - Objectives of Maintainability in the Design Review

SECTION 4C - PROCEDURES

Design Note 4C1 - Maintainability Design Review Checklist

SECTION 4D - MULTIPLEXER SET DESIGN REVIEW EXAMPLE

Design Note 4D1 - Presentation for a Critical Design Review (CDR)

4D2 - Preliminary Design Review (PDR)

SECTION 4A

DETAILED TASK DESCRIPTION

This section contains a description of the maintainability design review tasks and outlines the design review board activity.

SECTION 4A DETAILED TASK DESCRIPTION

DESIGN NOTE 4A1 - DESIGN REVIEW STRUCTURE

1. INTRODUCTION
2. MAINTAINABILITY ENGINEERING DESIGN REVIEW RESPONSIBILITIES
3. DESIGN REVIEW INPUT INFORMATION
4. DESIGN REVIEW OUTPUT INFORMATION

4 (1) Summary of Major Design Review Considerations

5. DESIGN REVIEW PROGRAM

DESIGN NOTE 4A1 DESIGN REVIEW STRUCTURE

1. INTRODUCTION

Design reviews are conducted throughout the product design cycle, in accordance with contract requirements, as an integral part of the contractor's system engineering review and evaluation program. The reviews are conducted so that particular aspects of the work or the entire system can be reviewed by a Design Review Board, an objective group of program personnel and specialists in the particular field. Reviews are scheduled and the board is appointed by the contractor's program management, upon recommendations of the various specialty groups, in order that deficiencies in equipment can be recognized to facilitate the implementation of timely and beneficial corrective action.

In addition to the chairman, the Design Review Board may include, but not be limited to, representatives of the following organizations: Maintainability, Reliability, Test and Evaluation, Design and Development, Manufacturing Engineering, and Quality. Consultants from outside agencies, vendor and subcontractor representatives, and military personnel may be included if appropriate. It is important that appointed representatives be technically qualified but not be so closely related to the product that an objective viewpoint is precluded.

Examples of the factors to be considered in a review (not necessarily in order of priority) are reliability, cost, environmental design, maintainability, human engineering, system concept, producibility, quality, test philosophy, installation, electrical design, mechanical design, thermal, safety, and standardization.

2. MAINTAINABILITY DESIGN REVIEW RESPONSIBILITIES

The activities that should be performed by the maintainability engineer as part of his design review responsibility are as follows:

a. Prepare and present quantitative assessment of maintainability.

b. Prepare and present task analyses, if required.

c. Prepare and present a list of design features that are most detrimental to maintainability or constitute a safety hazard.

d. Report any changes in maintenance concept or support equipment required as a result of design changes.

e. Present results of any trade-off analyses in which maintainability was a major contributor or impacted.

f. Recommend design changes that will improve maintainability or that will trade off excess maintainability to eliminate inadequacies in other areas.

g. Present interface problems.

h. Report progress toward milestones.

i. Report on personnel and skills required for system operation and maintenance.

j. Define preventive maintenance and corrective maintenance requirements.

3. DESIGN REVIEW INPUT INFORMATION

Information provided to the review team prior to the review must describe the item being reviewed and its requirements and interfaces. For example, component review for an item built in house might require the following documentation:

a. Detail drawing (pictorial representation, descriptions of required materials, finish, dimensions, tolerances, fabrication, and assembly instructions, etc.).

b. Installation drawing (general configuration, attaching hardware, and information to locate, position, and mount the item).

c. Circuit schematic diagram (function symbols with interconnections to illustrate circuit operation).

d. Component specification (functional characteristics and test requirement.

e. Data on parts and materials application.

f. Subsystem (or system) specification (for interface functional characteristics and test requirements).

g. System design data report (system description and specific design requirements such as space and weight considerations, mounting requirements, special environments, design and checkout requirements, maintenance provisions, etc.).

h. System design criteria report (general design philosophy and ground rules).

i. Reliability analyses and failure mode and effects analyses.

The last four documents listed provide interface information and should reflect the latest equipment operational profile. One task of the review effort will be to verify that all changes in the equipment's operational profile have been implemented and that the component requirements have been reevaluated. The major product of such a reevaluation of component requirements is assurance that the design is capable of performing any new task under possibly increased environmental stresses. The reevaluation also gives assurance that major design simplifications have been accomplished, when possible, to take advantage of associated reliability and cost benefits. This discussion is included here since the proposed evaluation of mission changes should be performed in the preparatory phase rather than during the design review meeting. The devotion of any portion of the design review effort to obsolete design criteria is thus avoided.

Subcontactor items receive similar consideration, except that the effort is usually divided into two phases: one at the contractor facility and one at the vendor facility. The initial phase includes revew of interface and installation documents, as described above, to confirm the accuracy of the requirements in the component (or procurement) specification. The procurement specification is usually expanded to include not only performance requirements but

component details such as external dimensions, finish, mounting surfaces, and simplified schematics, with specific design detail being left to the vendor, who must document and incorporate them into the specification.

In addition to the specific documents referenced above, a review requires other, more general types of information. Documented results of prior reviews, with management approval or disapproval and summaries of followup action, provide topics for current discussions. The designers must bring to the review all pertinent supporting data; e.g., design and laboratory notebooks, test reports, analyses, results of part and material application reviews, etc. Similarly, the reviewer should be prepared to support his position with data.

4. DESIGN REVIEW OUTPUT INFORMATION

Documentation of a design review must include the logic behind discussions about corrective action. The usual listing of action items is inadequate by itself, since the logic behind rejecting recommendations may be more significant. Design review is basically a management decision-making tool, and management interest at a later date may center on one of the "no action" items. The reason for repeated rejection of that item by the review team will assist management in evaluating new information. The same reasoning applies to later review efforts.

Design review documentation must record the team makeup, the review level, the input material, the decision items (not merely action items), and the decision logic when it is not evident. It must be of sufficient depth to be useful in subsequent reviews and to assist management in approving recommended action.

The report should have the concurrence of all review attendees. It should be prepared as the meeting progresses, with each item being resolved before the meeting continues. Although this may appear to be prohibitively time consuming, the advantages usually outweigh the inconvenience. The advantages include the following:

a. Added incentive for careful preparation. Prior research and written conclusions are more likely to receive recognition than an educated guess made during the review.

b. Added directional control of the meeting. The chairman has a valuable tool in immediate documentation because it tends to keep the meeting objectives in focus. By rephrasing discussion thoughts into wording suitable for the report, he continually directs attention to the need for applicable rather than extraneous data.

c. More accurate recording of consensus. Post-meeting documentation is dependent on one person's interpretation of meeting conclusions, and its preparation is usually delayed. Both of these conditions permit distortion.

d. Promotion of timely corrective action. Point-by-point agreement prevents major delays resulting from disagreement with the accuracy of the recorded version of the meeting.

If it is not considered feasible to prepare the report during the meeting, then, as a minimum, a summary agreed upon by all attendees must be written before the meeting ends. This summary will serve as the basis for the subsequent report.

5. DESIGN REVIEW PROGRAM

The design review meetings scheduled for any design program should include the design concept review, preliminary design review, and the critical design review. Details of each of these reviews are summarized in SN 5 (1) and discussed in detail in Section 4B.

SUB-NOTE 4(1) Summary of Major Design Review Considerations

Major Considerations	Design Concept Review	Preliminary Design Review	Critical Design Review
1. Select design alternative.	X		
2. Present maintainability block diagram.	X		
3. Review program data requirements.	X	X	X
4. Review adequacy of design information.	X		
5. Present maintainability prediction of selected design.		X	X
6. Present maintenance concept.		X	X
7. Present testing concepts.		X	
8. Review environmental constraints.		X	
9. Assure that all design requirements have been met.	X	X	X
10. Review all system trade-offs.		X	X
11. Present maintainability demonstration test results.			X
12. Recommend design changes as required.		X	X

SECTION 4B

GUIDELINES AND METHODOLOGY

This section contains the objectives of maintainability in the design concept review, preliminary design review, and critical design review.

SECTION 4B GUIDELINES AND METHODOLOGY

DESIGN NOTE 4B1 - OBJECTIVES OF MAINTAINABILITY IN THE DESIGN REVIEW

1. DESIGN CONCEPT REVIEW
2. PRELIMINARY DESIGN REVIEW
3. CRITICAL DESIGN REVIEW
4. CONTINUITY AND FOLLOWUP OF CORRECTIVE ACTION

DESIGN NOTE 4B1 OBJECTIVES OF MAINTAINABILITY IN THE DESIGN REVIEW

1. DESIGN CONCEPT REVIEW

The primary purpose of the design concept review is to make a choice from among alternative design approaches that may have evolved during the design process. The choice should be one of the following, in order of preference: (1) the simplest design that meets the maintainability requirements, (2) the design that has the highest maintainability, or (3) the design that shows the greatest promise of meeting the maintainability requirement.

The results of this first design review should include an understanding of the weak areas in the chosen design concept. A maintainability block diagram of the chosen design concept, showing the series and parallel elements, should also result from the review.

There should be an overall system concept to ascertain that the elements of the system are assigned the necessary and proper functions which will satisfy the required characteristics. Further, there should be a concept review of each system element to ascertain that its design will perform the assigned functions in the best possible manner.

The design concept review should also reveal any lack of data or need for more design information, such as the following:

a. Preventive and scheduled maintenance requirements
b. More information on hardware, construction, and accessibility
c. Diagnostic and testing schemes
d. Special facilities that may be required

2. PRELIMINARY DESIGN REVIEW

At this point, the initial system design is nearly complete and many component parts and assemblies will have undergone some development testing. Some of the factors to be considered at this review are adherence to specifications,

reliability, maintainability, safety of personnel, appearance and human engineering factors, economy of manufacture, environmental adequacy, and compatibility.

To estimate if the design will meet the maintainability requirement, a maintainability prediction must be made. Chapter 13 presents the appropriate prediction techniques.

If the prediction indicates that the maintainability requirement will not be met, then a management decision should be made whether to abandon the present design and start again or concentrate effort on improving the design.

If improvement is needed, areas that require more attention should be identified. This is the point at which design decisions may be required as to redundancy versus rapid fault isolation techniques, or redesign of inaccessible areas versus a search for high-reliability parts. The latter is a typical example of the extensive interface between maintainability and reliability.

Planning should precede the meeting to ensure that the design review is patterned to the design. Any misapplications should be identified in the meeting. Questionable areas, such as those in which severe environmental conditions appear to be troublesome, should become evident. Some problems may be identified that should be earmarked for subsequent attention under the category of designing for reliability.

In analyzing the results of this design review, management should determine whether decisions made in the previous design review were valid, and how to plan the continuation of the design phase.

3. CRITICAL DESIGN REVIEW

After changes as indicated in the previous design review are incorporated, the product has matured into the final stage. The purpose of the critical design review is to assure that all the requirements have been met.

No individual should be held responsible for remembering all of the detailed information accumulated to this point in a particular design, or for remembering which details must be considered in the final design review. The most common errors evolving from such a review are errors of omission. Therefore, the most useful tool in such a review is a detailed checklist. Each design requires its checklist, which should be carefully prepared, in a joint effort, by design and maintainability personnel. (A typical design review checklist for maintainability is presented in Section 4C.)

Meeting design requirements is the prime consideration in the critical design review. For the maintainability requirement, another maintainability prediction must be performed. Close collaboration by maintainability, reliability, and design personnel throughout the whole design phase is essential.

At this point, the production design of the system is essentially complete and the system is considered ready for production. This review should place special emphasis on attainment of minimum life cycle cost for the system.

4. CONTINUITY AND FOLLOWUP OF CORRECTIVE ACTION

If the potential design improvement afforded by the design review program is to be realized, continuity must be maintained from meeting to meeting, and recommendations must be followed up until corrective action has been taken. Sufficient information must be carried over to successive reviews to avoid redundant coverage of problems.

Continuity is difficult to achieve. Documentation provides a degree of continuity, but probably will not be sufficient to assure efficient information transfer. Complete personnel continuity is neither practical nor profitable.

The same personnel are seldom available for repeated review team assignments over an extended period, and they can seldom handle all levels of review. It may be possible for a permanent chairman to conduct all reviews on a given subsystem and its components.

Followup is necessary to assure that the benefits actually accrue and to verify that appropriate design change action has been taken, or that additional study has validated the original design. In one approach, the recommendations incorporated directly into the hardware corrective action process and the existing followup mechanism are used to assure the same management scrutiny of corrective action that hardware problems receive.

SECTION 4C

PROCEDURES

This section contains procedures for using a maintainability design review checklist to assure that no maintainability design attributes have been overlooked.

SECTION 4C PROCEDURES

DESIGN NOTE 4C1 - MAINTAINABILITY DESIGN REVIEW CHECKLIST

1. SPECIFIC DESIGN REVIEW SUBJECTS

2. GENERAL DESIGN REVIEW CHECKLIST

2 (1) MAINTAINABILITY DESIGN REVIEW CHECKLIST

DESIGN NOTE 4C1 MAINTAINABILITY DESIGN REVIEW CHECKLIST

1. SPECIFIC DESIGN REVIEW SUBJECTS

The first step in a design review is to compile a list of all the maintainability requirements and maintainability-related requirements, relative to the item(s) being reviewed.

These requirements may be derived from the following sources:

a. Specifications
   System
   Configuration Item (CI)
b. Trade study results
c. Models
d. Program direction
e. Customer direction

As a part of the review, it should be verified that each requirement is satisfied.

2. GENERAL DESIGN REVIEW CHECKLIST

For the wide diversity of present and future Air Force programs, the design review function, no matter how applied, should cover certain equipment attributes. Use of a design review checklist alone cannot assure better equipment, but it is one means of assuring that no essential design attributes have been overlooked.

The checklist presented in SN 2 (1) was adapted from a list compiled by the Aerospace Communications and Control Division of RCA and published in Electronic Design magazine.

SUB-NOTE 2 (1). (Sheet 1 of 7 sheets) Maintainability Design Review Checklist

ELECTRICAL DESIGN
Maintenance
Are maintenance and test equipment requirements compatible with the concept established for the system?
Does the unit require special handling?
Can the unit be readily installed and connected to the system?
Are factory or depot adjustments made in such a way that they do not require readjustment when units are replaced in a system or when parts are replaced in the unit in the field?
What adjustments are necessary after a unit has been installed in the system?
Can adjustments compensate for all possible tolerance buildup?
Is periodic alignment or adjustment recommended? How often?
Can the specified time limitations of maintenance tests be met?
Has the number of depot and field adjustments been minimized?
Are interconnected circuits located in the same package, thus providing minimal inputs and outputs at each maintenance level?
Is the design such that the circuit cannot be damaged by careless use of an adjustment or combination of adjustments?
Are adjustments and indicators of the "center zero" type used where possible?
Is periodic testing necessary? How often?
Are the test points adequate? Are they accessible?
What overhaul testing is required?
What specific test equipment is necessary?
Have factory and maintenance test equipment requirements been minimized and coordinated with the requirements for other units?
What special techniques are required in the repair, replacement, or alignment of the unit?

SUB-NOTE 4 (1) (Sheet 2 of 7 sheets) Maintainability Design Review Checklist

Maintenance (continued)

Are parts, assemblies, and components placed so that there is sufficient space to use test probes, soldering irons, and other tools without difficulty?

Are testing, alignment, and repair procedures such that a minimum of knowledge is required on the part of maintenance personnel? Can troubleshooting of an assembly be performed without removal from a major component?

What special tools or test equipment are required?

Can every fault (degrading or catastrophic) that can possibly occur in the unit be detected by the use of the proposed test equipment and standard test procedures?

Have parts subject to early wearout been identified? Have suitable preventive maintenance schedules been established to control these parts?

Are the components with the highest failure rates readily accessible for replacement?

Are parts mounted directly on the mounting structure rather than stacked one on another?

Are units and assemblies mounted so that the removal of one does not require removal of others?

Are limiting resistors used in test point circuitry; i.e., is any component likely to fail if a test point is grounded?

Can panel lights be replaced easily? (Panel lights should not be wired in series.)

Have voltage dividers been provided for test points for circuits carrying more than 300V?

Will the circuit tolerate the use of a jumper cable during maintenance?

Are controls located where they can be seen and operated without disassembly or removal of any part of the installation?

Are related displays and controls on the same face of the equipment?

Are all units (and parts, if possible) labeled with full identifying data? Are parts stamped with relevant electrical characteristics information?

SUB-NOTE 2 (1) (Sheet 3 of 7 sheets) Maintainability Design Review Checklist

Maintenance (continued)

Are the connecting cables of each functioning unit long enough to permit moving the unit for convenient checking?

Are plugs and receptacles used for connections rather than "pigtails" to terminal blocks?

Are field replaceable modules, parts, and subassemblies plug-in rather than soldered?

Are cable harnesses designed for fabrication as a unit in a shop?

Are cables routed to preclude pinching by doors, covers, etc.?

Is each pin on each plug identified?

Are plugs designed to preclude insertion in the wrong receptacle? Are plug-in boards keyed to prevent improper insertion?

Has a suitable scheduled maintenance program been established?

System and Circuit Considerations

Do self-test features of a unit meet applicable requirements?

What system adjustments are required when a unit is replaced?

Are there firm specifications for this circuit, including test specifications?

Can any unreasonable or unusually difficult requirement be relaxed?

Do weight-reduction considerations affect maintainability?

Safety Factors

Is there adequate protection against dangerous voltages?

Are high-voltage warning plates necessary?

Have interlocks, safety switches, and grounding bars been considered?

Are all external metal parts at ground potential?

Are discharging rods necessary to discharge large capacitors?

Are bleeder and current-limiting resistors used in power supplies?

Are there burning hazards?

SUB-NOTE 2 (1) (Sheet 4 of 7 sheets) Maintainability Design Review Checklist

Safety Factors (continued)

Are "hot" terminals exposed when plugs or connectors are not connected?

Are adjacent plugs or connectors keyed to prevent interchanging of connections?

Can maintenance or adjustment be performed safely?

MECHANICAL DESIGN

Maintainability Design

Is each assembly self-supporting when in the desirable position for easy maintenance?

Can assemblies be laid on a bench in any position without damaging components?

Testing

Are the test processes the lowest cost consistent with meeting the design requirements?

Can any test specification be eliminated or relaxed?

Have interacting controls been eliminated or the adjustments specified in such a manner that the lowest salaried factory test personnel can easily align the circuit?

Is the system compatible with the requirements for checkout in the factory, if not as a complete system, then in large subsystem segments?

Have test process experts been consulted for alternatives that would keep test costs down?

General Design

Has the chassis been properly designed?

In the case of terminal boards, are the critical components mounted at the edges rather than at the center, and are they properly supported?

In the case of lead-mounted parts, have component weight, lead weight, thermal expansion, supplementary support, bend rate, and other mounting considerations been evaluated?

Have clearances been provided with due consideration for vibration, shock, and noise stresses?

SUB-NOTE 2 (1) (Sheet 5 of 7 sheets) Maintainability Design Review Checklist

General Design (continued)

Can electrical reliability be caused by vibration of mechanical parts?

Have shock and vibration tests been performed?

Are heat-dissipating elements properly located with respect to heat-sensitive parts? Is there suitable flow of air?

Have component parts, subassemblies, and assemblies been supported and clamped properly, with adequate consideration for heat dissipation?

Is the unit of the lightest weight consistent with sturdiness, safety, and reliability?

Are all items visually and physically accessible when the unit is on the test stand?

Is the possibility of physical damage from misuse of adjustments minimized?

Is the possibility of damage to the unit during handling and installation minimized?

Can the unit be removed and replaced within the required time limit?

Is the packaging scheme such that unrealistic spare parts requirements are avoided?

Are all fasteners large enough?

Are guide pins, keys, and latches strong enough?

Is the basic structure strong enough?

Are parts located to provide for logical wiring?

Are lubrication points minimized? Where required, are they accessible and clearly marked?

Have unit environment tests, including temperature measurement at key points, been completed?

Has a separate list of recommendations for product improvement or redesign been compiled?

What alternate designs were considered?

SUB-NOTE 2 (1) (Sheet 6 of 7 sheets) Maintainability Design Review Checklist

General Design (continued)

Have the appropriate standards been consulted for materials, components, drafting, manufacturing, and workmanship?

What factors influenced the choice of this particular design?

Do firm specifications, including test specification, exist?

Have all specifications been met?

Does any specification require modification?

Can any unreasonable or unusually difficult requirements be relaxed?

Workmanship and Maintainability

Is soldering adequately specified? What provisions have been made to prevent cold joints and to ensure removal of flux?

Are proper screw lengths and locking provisions specified?

Are designs such that damage to components during installation is prevented?

Have guide pins been provided to facilitate installation of plug-in units?

Are plug-in units keyed (by some means other than the connector) to prevent accidental insertion in the wrong location?

Have tolerances of component-mounting provisions and mating holes been coordinated?

Have all holes been located far enough from bends to prevent distortion?

Are bend radii specified to be large enough, in accordance with appropriate standards?

Have the following items been considered for wiring and cabling:

Are cables led properly around corners and sharp edges?

Are grommets provided where needed?

Is the design such that soldering-iron burns during both manufacture and maintenance are minimized?

Is lacing properly and adequately specified?

SUB-NOTE 2 (1) (Sheet 7 of 7 sheets) Maintainability Design Review Checklist

Workmanship and Maintainability

Have harnesses been properly routed, and has sufficient clamping been provided to prevent cables from hanging loose?

Has adequate space been allowed for harnesses and for breakouts to connectors, etc.?

Are heavy wires brought to large enough terminals?

Are stranded wires properly secured close to solder joints to prevent flexing?

Is any cable (or wire) overly taut, with strain placed on the connector, the cable (or wire), or the clamps?

Do any cables or wires lie across removable units or across fasteners of any type?

Are all connectors visible, and are they easily accessible to tools and hands?

Have cables (wires) and connectors been properly identified? Can wrong connections result from cable layout and connector type?

Do any cable (wire) runs permit contact between the cable (wire) and moving parts?

Are all items (parts and subassemblies) visually and physically accessible for assembly, wiring rework, and maintenance?

Are all test points accessible when the unit is properly installed?

Are all field adjustments accessible when the unit is properly installed?

Has sequential assembly been avoided to prevent involved sequential disassembly to make repairs and adjustments?

Is the design such that no unrealistic requirements for special maintenance, storage, or shipment facilities are imposed?

Is the design such that no unnecessary requirements for a special maintenance environment (e.g., ground power carts, cooling, special primary power, etc.) are imposed?

Does the design provide for adequate protection of maintenance and test personnel against accidental injury?

SECTION 4D

MULTIPLEXER SET DESIGN REVIEW EXAMPLE

This section contains an example of presentation data and minutes of the meetings of design reviews from the Multiplexer Set sample system.

SECTION 4D MULTIPLEXER SET DESIGN REVIEW EXAMPLE

DESIGN NOTE 4D1 - PRESENTATION FOR A CRITICAL DESIGN REVIEW (CDR) FOR THE MULTIPLEXER SET

1. MAINTAINABILITY PRESENTATION
1.1 Requirements
1.2 Detailed Presentation
1.2.1 On-Line Maintenance Engineering Change Proposal (ECP)
1.2.2 Maintainability Demonstration
1.3 Discussion
1.3.1 Discard-at-Failure Maintenance
1.3.2 Diagnostics
1.3.3 Timer Oscillator Stability
1.4 Summary Statement
1.5 Post-Review Action Items
1 (1) Multiplexer Set (Front View)
1 (2) Multiplexer Set (Side View)
1 (3) Multiplexer Set Maintenance Control and Displays
1 (4) Most Frequent Maintenance Tasks
1 (5) Multiplexer Set Test Points
1 (6) Multiplexer Set Tools
1 (7) Multiplexer Set Test Equipment
1 (8) Multiplexer Set Preventive Maintenance
1 (9) Multiplexer Set Current Maintenance Time Data
1 (10) Multiplexer Set Maintainability Program Schedule

DESIGN NOTE 4D2 - PRELIMINARY DESIGN REVIEW (PDR) MEETING FOR MULTIPLEXER SET

1. RELIABILITY AND MAINTAINABILITY MEETING MINUTES
1.1 Attendees
1.2 Minutes of the meeting
1.3 Addendum

DESIGN NOTE 4D1 — PRESENTATION FOR A CRITICAL DESIGN REVIEW FOR THE MULTIPLEXER SET

1. MAINTAINABILITY PRESENTATION (See SN 1(1) through SN 1(10).)

1.1 Requirements

Maintainability Program Plan, CDRL Item B026.

1.2 Detailed Presentation

Maintainability characteristics of the Multiplexer Set were presented as defined in SN 1(1) through SN 1(10).

1.2.1 On-Line Maintenance Engineering Change Proposal (ECP)

The basic performance characteristics proposed in the on-line maintenance ECP were informally presented. This presentation was primarily for purposes of orientation for those persons not previously familiar with the proposed concept.

1.2.2 Maintainability Demonstration

Attendees were familiarized with the mechanical features of the Multiplexer Set and differences between it and the eight prototype units to be built.

A number of simulated malfunctions were introduced into both channel and common electronic portions of the multiplexer. The resultant front panel error display was then viewed to establish correlation between malfunction and diagnostic callout. The effect of a malfunction inserted in the overhead data generator was discussed, using its associated logic diagram. All simulated malfunctions produced the proper front panel display.

1.3 Discussion

1.3.1 Discard-at-Failure Maintenance

Annex No. 2 to the Statement of Work sets forth the guidelines to be used in considering the use of discard-at-failure maintenance. The decision to repair or discard failed circuit card modules will depend on results of trade-off studies made by the contractor. Data from these studies will be provided as part of subsequent Maintainability Program Status Reports (CDRL, Item B033).

Discussion of the card and module discard versus repair decision led to a discussion of the type of conformal coating planned for Multiplexer Set application. It was stated that if the cards are to be repaired, any conformal coating would be selected so as to permit such repair. Attendees agreed that this approach was acceptable.

A discussion of the methods to be used for the detailed isolation of defective cards centered about the use of a tape-controlled test set similar to that presently used in the engineering test program. Such an item of AGE will be recommended by the contractor if card repair versus throwaway analysis indicates repair to be most economical for the Government.

1.3.2 Diagnostics

The following statements were provided by customer personnel:

> "As a matter of information, the present diagnostic design does not distinguish between a line/data problem and a physical equipment problem in certain areas. For example, the detection and display by the equipment of an out-of-tolerance input timing condition may also yield an indication of internal equipment failure. This possibility should be noted in the tech orders for maintenance information/guidance."

Note: The contractor states that this condition will be corrected during design updating for the prototype Multiplexer Set models.

1.3.3 Timer Oscillator Stability

As a result of discussions regarding potential future use of a reference timing oscillator with a stability of one part in 10^8, the following statements were provided by customer personnel:

> "The Hewlett-Packard Model M54-5245M Frequency Counter to be recommended by the contractor as an item of AGE to calibrate the one part in 10^6 stability clock currently specified will not be suitable for use in maintaining a higher stability clock at one part in 10^8 (or five parts in 10^8) is in fact required, a different (and more expensive) item of AGE will be required."

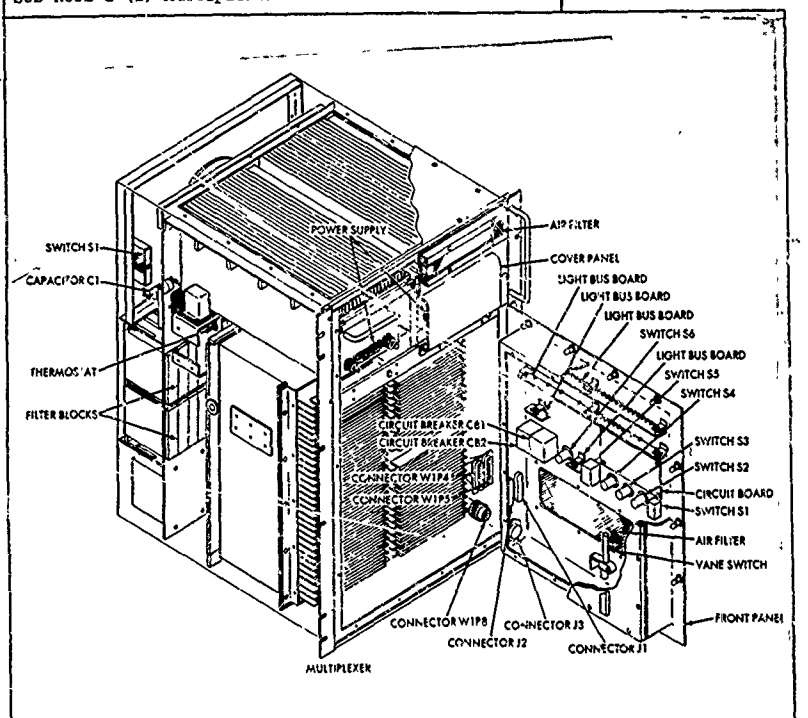
1.4 Summary Statement

The information and data presented reflect basic design compliance with maintainability performance requirements defined in Annex No. 2 of the Statement of Work and applicable portions of the equipment specifications.

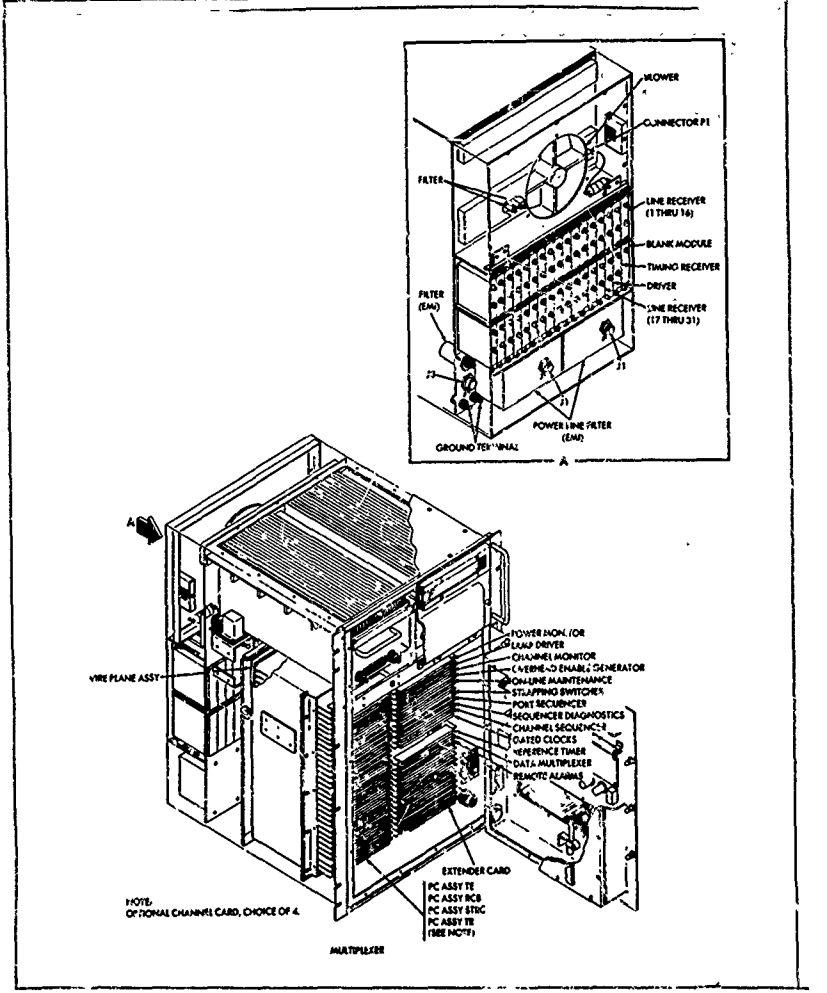
1.5 Post-Review Action Items

a. Complete discard-at-failure vs. repair trade-off study	a. Results to be included in May 1971 submittal of B033.
b. Submit AGE recommendations	b. Planned submittal of B037 in April 1971.

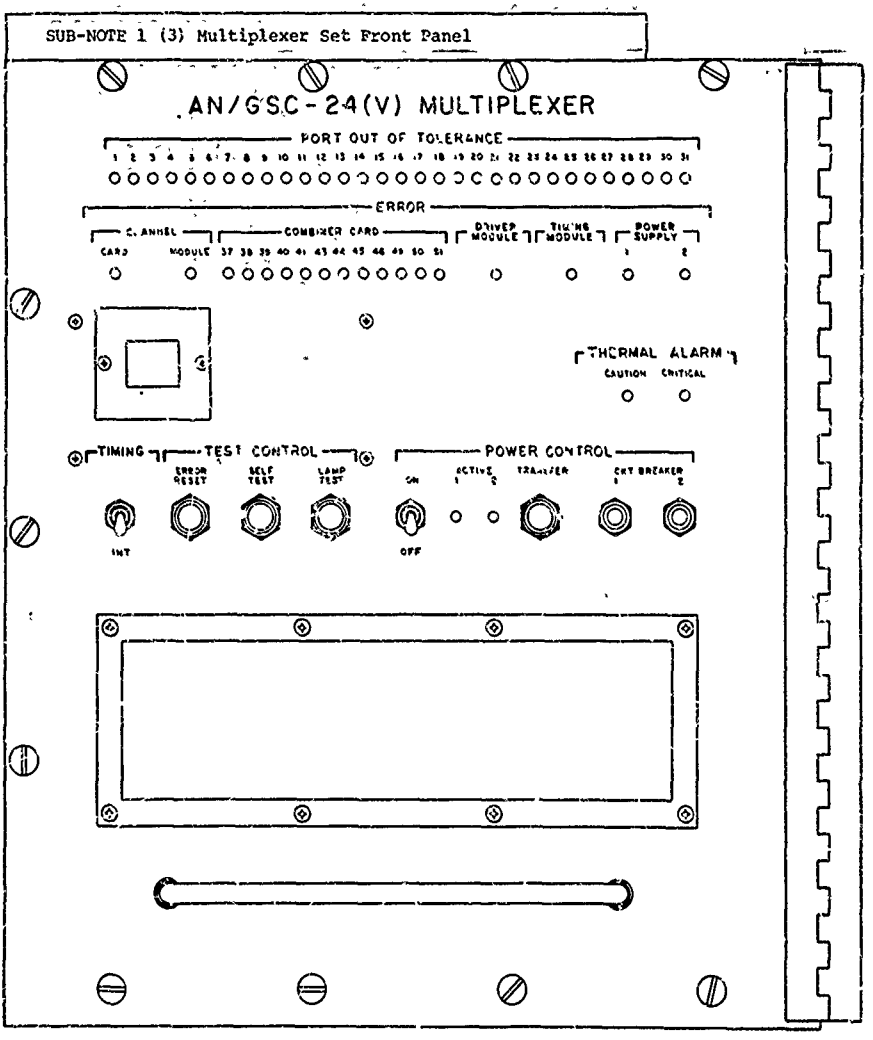
SUB-NOTE 1 (1) Multiplexer Set



SUB-NOTE 1 (2) Multiplexer Set With Rear View



SUB-NOTE 1 (3) Multiplexer Set Front Panel



SUB-NOTE 1(4) Most Frequent Maintenance Tasks

	Item	% Failures	Time	Tools
1.	PC Card	65.0	3.7	Screwdriver
2.	I/O Module	19.0	6.9	Screwdriver
3.	Power Supply	6.1	10.3	Screwdriver
		90.1		

SUB-NOTE 1(5) Multiplexer Set Test Points

- General Arrangement

TP1	Major Input
$TP2\text{-}TP_{n-2}$	Interim Points
TP_{n-1}	Major Output
TP_n	Diagnostic Output

- Identification

  Each Point Numbered on Board

- Quantity (Set, 31 RCB/SB)

Mux	356
Demux	354
	710

- Other Points

  All Card Connector Pins via Extender

SUB-NOTE 1(6) Multiplexer Set Tools

- Standard and Common

  Conventional Hand Tools

- Special

  Printed Circuit Card Extender (W/Equipment)

  Wire Wrap Repair Kit

  Wire Wrap Tool*

  Bit*
  Sleeve*
  Knife*
  Holder*
  Cut/Strip Accessory

  Wire Removal Tool*

*Federal Stock Number (FSN) Is Assigned.

SUB-NOTE 1(7) Multiplexer Set Test Equipment

- Standard and Common

  1. Oscilloscope, Tektronix Type 454*

Bandwidth	-	150 MHz
Rise Time	-	2.7 Nanoseconds
Input Power	-	115V, 50-400 Hz, 1Ø

  2. Frequency Counter, Hewlett-Packard M54-5245M

Input Range	-	0 to 50 MHz
Display	-	8 Place, Digital
Stability	-	5 Parts/10^{10}/Day Long Term

  3. Multimeter AN/PSM-6A*

- Special

  None Required (Built-in Diagnostic)

  *Federal Stock Number (FSN) Is Assigned.

SUB-NOTE 1(9) Multiplexer Set Preventive Maintenance

Task	Interval	Downtime
Clean Air Filters	30 Days	No
Visual Inspection	30 Days	No
Timing Calibration	30 Days	No
Blower Replacement	5 Years	Yes

SUB-NOTE 1(9) Multiplexer Set Current Maintenance Time Data

$\overline{M}_{ct}$

Required - 12.0 Minutes

Predicted - 8.0 Minutes

$M_{max\ ct}$ (95th Percentile)

Required - 36.0 Minutes

Predicted - 18.3 Minutes

SUB-NOTE 1 (10) Multiplexer Set Maintainability Program Schedule

	N	D	J	F	M	A	M
Analysis & Status Report	■						
Prediction (Update)	■						
ACS Recommendations							
Calibration Requirements Summary							
DAF/RAF Study (Update)							

DESIGN NOTE 4D2 — PRELIMINARY DESIGN REVIEW MEETING FOR MULTIPLEXER SET

1. RELIABILITY AND MAINTAINABILITY MEETING MINUTES

1.1 Attendees

The list will include all persons present at the meeting.

1.2 Minutes of the Meeting

a. Implementation of the RCB and STRC diagnostic design was reviewed. A block diagram level discussion of previous and current RCB diagnostic designs was presented by the contractor.

b. Data supporting the current $\overline{M}_{ct}$ and $M_{max\ ct}$ predictions were reviewed. The contractor prediction technique, which combines flow diagramming and MIL-HDBK-472, Method III, procedures, is acceptable for continued use. Specific elemental task times remain subject to Air Force review.

c. The contractor will investigate the practicality of automatically detecting air blower failures.

d. Based upon current field maintenance procedures, on-line repair is considered highly desirable for the following items:

(1) Channel-related printed circuit cards and modules.

(2) Panel lamps and displays.

(3) Cooling air blowers (if possible before reaching a critical rise in temperature).

(4) Power supplies (not feasible with certain designs).

e MTBF, $\overline{M}_{ct}$, and $M_{max\ ct}$ calculations shall be consistent with each other and consistent among reports, manuals, and other applicable documents.

f. Limited life items (such as blowers and panel lamps) shall be identified and planned replacement intervals determined by the contractor.

g. The contractor will investigate alternate approaches to repair of power supply failures as follows:

(1) Alternative No. 1 - Initiate power supply repair within a specified time period after failure of one of the supplies.

This procedure is preferable if the Multiplexer Set is not used continuously. This alternative maximizes the equipment reliability but places a limitation upon continuous operation. This is the procedure presently used in the $\overline{M}_{ct}$ calculations.

(2) Alternative No. 2 - Initiate power supply repair only after both power supplies have failed. This alternative is desirable if continuous operation is required, as it is consistent with the objective of no downtime for preventive maintenance. It is also the approach presently used for the MTBF calculation. This approach will increase the power supply repair time but will probably have an insignificant effect upon the average repair time.

h. The reliability prediction was presented during the general meeting on July 13. The details of the prediction were reviewed during the reliability special meeting on July 14 and 15. The basic reliability prediction indicated an MTBF of 1955 hours. This estimate is based on a 25°C ambient operating temperature. It represents a complete multiplexer set, including 31 RCB's, 31 SB's, and power supplies. The prediction presented at this time is based on preliminary circuit diagrams for the multiplexer circuits, and drivers and smoothing buffers for the demultiplexer. The prediction includes estimates of circuit complexity for the power supplies, demultiplexer common electronics and demultiplexer timing circuits. Failure rate sources used are RADC-TR-67-208, Vol. II, for discrete electronic part failure rates, RADC source information for integrated circuits and TX semiconductor improvement factors, RADC-TR-69-458 for nonelectronic part failure rates. The failure rate estimate for the power supplies is based on an estimated 4.0 failures per 10^6 hours per voltage output. In addition, a failure rate of 3.0 failures/10^6 hours for the sensing and logic circuits is assumed. The total failure rate for the redundant power supplies is 2/3 the failure rate of a single unit.

An analysis of the reliability effect of using a thick film hybrid microelectronic configuration for line drivers and line receivers was made. The model used to estimate the failure rate of the hybrid circuit is based on an RADC proposed prediction model. This analysis shows a potential increase of approximately 100 hours in the MTBF of the Multiplexer Set.

i. Preliminary comments on the Reliability and Maintainability Program Plans and reliability and maintainability allocations, assessments, and analysis reports were reviewed.

j. Conclusions and action items:

(1) The MTBF estimate of 1955 hours is less than the specified MTBF of 2200 hours. The contractor does not anticipate a problem in meeting the requirement. The contractor will emphasize reduction in complexity and improved temperature conditions to achieve the improvement.

(2) RADC will investigate the possibility of providing a computer program to calculate the MTBF estimates.

(3) Functional and reliability block diagrams will be provided with the reliability prediction.

1.3 Addendum

The contractor described a proprietary power supply design offering potential improvements in efficiency, size, and reliability. Optimum use of this type of power supply would require a change in contract specifications with regard to the method of redundancy. This power supply is adaptable to internal rather than external redundancy with further improvements in weight, efficiency, maintainability, and reliability. Using this technique, on-line power supply repair may become achievable. RADC representatives agreed that the procedure should be investigated and a decision would be made after the contractor performs a trade-off study of the effects of the change.

CHAPTER 5

MAINTAINABILITY ALLOCATIONS

This chapter contains a detailed task description, guidelines, methodology, and procedures of the maintainability allocations. It also includes an example of the Multiplexer Set allocations.

CHAPTER 5 MAINTAINABILITY ALLOCATIONS

SECTION 5A - MAINTAINABILITY ALLOCATIONS INTRODUCTION

Design Note 5A1 - Detailed Task Description

5A2 - Cuidelines and Methodology

5A3 - Allocation Procedures

SECTION 5B - MAINTAINABILITY ALLOCATIONS FOR THE MULTIPLEXER SET

Design Note 5B1 - Multiplexer Set Requirements

5B2 - Maintenance Time Allocation

SECTION 5A

MAINTAINABILITY ALLOCATIONS INTRODUCTION

This section contains a detailed task description, guidelines, methodology, and procedures for the maintainability allocations.

SECTION 5A MAINTAINABILITY ALLOCATIONS INTRODUCTION

DESIGN NOTE 5A1 - DETAILED TASK DESCRIPTION

1. GENERAL

DESIGN NOTE 5A2 - GUIDELINES AND METHODOLOGY

1. GENERAL

2. MAINTAINABILITY ESTIMATES FOR SYSTEM COMPONENTS

2(1) Guide for Initial Maintainability Estimates

DESIGN NOTE 5A3 - ALLOCATION PROCEDURES

1. ALLOCATIONS

DESIGN NOTE 5A1 DETAILED TASK DESCRIPTION

1. GENERAL

The maintainability engineer will begin the maintainability design process with one or more specific maintainability objectives that may be expressed in any one of a variety of ways, i.e., $\overline{M}_{ct}$, $M_{max\ ct}$, etc.

As an aid to achieving system maintainability objectives, these objectives are translated into detailed maintainability requirements for system components. This process is known as maintainability allocation.

Maintainability allocations are performed for the following purposes:

a. To provide guidelines to designers so that the final product meets the overall system maintainability requirements.

b. To provide a procedure for maintainability bookkeeping based on a logical distribution of the overall maintainability requirements.

c. To provide a maintainability management tool to system contractors when several vendors are involved.

Allocations are made by the Air Force, by its contractors, or by both. If the Air Force is to perform the system integrating function, the responsible Government agency performs the allocation and includes the results as requirements in the separate contracts to the various subsystem contractors. For systems being integrated by a contractor, the integrating contractor is responsible for overall system maintainability; he must perform the allocation and assure that his subcontractors comply with their individual requirements.

DESIGN NOTE 5A2 GUIDELINES AND METHODOLOGY

1. GENERAL

Allocations need only be made to the level of hardware and maintenance which has a direct bearing on the value of the maintainability indices being allocated. If, for example, the $\bar{M}_{ct}$, at organizational level is being allocated and the LRU is spared on base, the field maintenance time has no direct bearing on organizational time and therefore is not part of the allocation. In this case, one would only allocate to the LRU from the system. For this case, the maintenance time for the LRU in the shop should be a fallout of that design and maintenance concept which represents the lowest life cycle cost.

Maintainability allocation can be performed using two forms of data: (1) an estimate of the average maintenance time expected for each item of equipment relative to one particular item; and (2) an estimate or apportionment of the failure rate distribution among the equipments when configured as a system or set. Neither form of data need be known in terms of real values such as minutes of downtime or failures per hour. Relative maintenance time can be estimated in terms of a reference value X, and estimated failure rate in terms of failure percentage associated with each item of equipment. In both cases, the estimate need only be in terms of a ratio and as such is subject to less error than techniques based on estimates of absolute values. Being a ratio, any constant error in the absolute value cancels out. The following example illustrates this allocation technique.

Example:

Assume a system comprised of three items of equipment which, in combination, must demonstrate a mean corrective maintenance time ($\bar{M}_{ct}$) of 12.0 minutes. Let an estimate of the $\bar{M}_{ct}$ associated with one item of equipment equal an

arbitrary value X. Further assume that due to complexity, type, or other factors, the estimated $\overline{M}_{ct}$ of the second item relative to the first is one and one-half times that of the first (1.5X), and the $\overline{M}_{ct}$ of the third item relative to the first is three-quarters that of the first (0.75X).

When the three items are configured as a system, let the first be expected to contribute 50 percent of the total failures, with the second contributing an expected 30 percent, and the third an expected 20 percent. That portion of the allowed 12.0 minutes system $\overline{M}_{ct}$ to be allocated to each equipment can then be established by solving the following equation for the unknown value X:

$$(0.50)\ (X) + (0.30)\ (1.5X) + (0.20)\ (0.75X) = 12.0 \text{ minutes}$$

$$1.10\ X = 12.0 \text{ minutes}$$

$$X = 10.9 \text{ minutes}$$

Hence, the apportioned $\overline{M}_{ct}$ for the first item of equipment is X or 10.9 minutes, for the second 1.5X or 16.35 minutes, and for the third 0.75X or 8.18 minutes.

This allocation technique allocates maintainability values to lower levels of hardware such that the system requirement is met regardless of whether or not the original basis for estimate value for an item may have resulted in an improvement in the system requirement. Any improvement in the system requirement should be predicated on life cycle cost studies rather than on allocations. The results of an allocation should be coordinated with the appropriate design agencies to verify that the values obtained are feasible.

2. MAINTAINABILITY ESTIMATES FOR SYSTEM COMPONENTS

Initial estimates of maintainability or maintainability ratios must be made for each affected item. The estimates must be made in the same units of measure as the maintainability objective. The estimates may be derived from any of the following sources:

Predictions

Data on similar components

Experience with similar components

Engineering estimates based on personal experience and judgment.

Attempts to make maintainability estimates for system components are most often frustrated by the following:

Prediction techniques are not applicable at this level of maintenance.

Prediction techniques are applicable to this maintenance level, but the units of measure of maintainability are not consistent with the objective.

No suitable historical data are available.

This system incorporates new design concepts whose impact on maintainability is not known.

SN 2 (1) [illegible] guide to the methods to be used in initial maintainability estimates for system components. The order in which the methods are shown is generally in the descending order of their expected order of accuracy.

Another approach to making maintenance time estimates is illustrated in DN 5B2 (para. 2).

SUB-NOTE 2 (1) Guide for Initial Maintainability Estimates

Units of Measure	Description of Block Maintenance Philosophy				
	Assembly		LRU		Equipment
	Replace	On-Equipment Repair	Replace	On-Equipment Repair	On-Equipment Repair
$\overline{M}_{ct}$	1,2,4	1,2,4	1,2,4	1,2,3,4	1,2,4
MMH/OH	1,4	1,4	1,4	1,4	1,4
$\tilde{M}_{ct}$	1,4	1,4	1,4	1,4	1,4
M_{ct} and M_{max}	1,2,4	1,2,4	1,2,4	1,2,4	1,2,4
$\tilde{M}_{ct}$ and M_{max}	1,4	1,4	1,4	1,4	1,4

KEY: Method 1 - RADC/ARINC Prediction Technique, RADC-TR-69-356, Volume I
2 - Procedure III, MIL-HDBK-472
3 - Maintainability Prediction by Function - ARINC Research Corporation
4 - Data and Experience on Similar Components

DESIGN NOTE 5A3 ALLOCATION PROCEDURES

1. ALLOCATIONS

The basic steps in developing the maintainability allocation are as follows:

a. Obtain the value of the top level maintainability indices for which the allocation is to be made.

Call this $\underline{M}_R$ required maintainability indices.

b. Select one item in the allocation as a unit reference item for the $\underline{M}$ indices being allocated. Call this X. The one selected will normally be the one with which the engineer is most familiar.

c. Estimate each other item $\underline{M}$ indices as some multiplication factor of X; for example, 1.25X or $\underline{M}_m$ *X.

d. Estimate the failure rate contribution of each item to the total failure rate of all items in the allocation.

Call this fc.

$$\text{where } fc_i = \frac{\lambda_i}{\lambda_t}$$

where λ_i = failure rate of the ith item

λ_t = total failure rate of all items in the allocation.

e. Solve the following equation for X:

$$\underline{M}_R = \sum_{i=1}^{n} fc_i * \underline{M}_m * X$$

or

$$\underline{M}_R = fc_A * \underline{M}_{mA} * X + fc_B * \underline{M}_{mB} * X + \cdots + fc_n * \underline{M}_{mn} * X$$

where A,B,****,N refers to the items being allocated to.

f. The allocated maintainability indices value for each item is the value of X times the value of $\underline{M}_m$ for that item.

SECTION 5B

MAINTAINABILITY ALLOCATIONS FOR THE MUTLIPLEXER SET

This section illustrates details of the processes involved in maintainability allocation by presenting an example of the allocation for the Multiplexer Set. The example includes the maintainability allocations, assessments, and analysis.

SECTION 5B MAINTAINABILITY ALLOCATIONS FOR THE MULTIPLEXER SET

DESIGN NOTE 5B1 - MULTIPLEXER SET REQUIREMENTS

1. BACKGROUND

DESIGN NOTE 5B2 - MAINTENANCE TIME ALLOCATION

1. GENERAL
2. MEAN MAINTENANCE TIME ESTIMATION
2(1) Simplified Maintenance Flow
2(2) Simplified Repair Flow
2(3) Maintenance Function Time Estimates
2(4) Failure Rate Distribution (Percent)
2(5) Estimated Maintenance Time Computation
3. MEAN MAINTENANCE TIME ALLOCATION
4. MAXIMUM MAINTENANCE TIME ALLOCATION
5. SUMMARY OF ALLOCATED MAINTENANCE TIMES
5(1) Summary of Allocated Maintenance Times

DESIGN NOTE 5B1 — MULTIPLEXER SET REQUIREMENTS

1. BACKGROUND

The Multiplexer Set and ancillary equipments are being developed in accordance with requirements set forth in the Statement of Work and the specifications.

These documents require that design of the Multiplexer Set enable attainment of a mean time between failure (MTBF) of not less than 2200 hours, and upon failure, be restored to operation within a mean corrective maintenance time ($\bar{M}_{ct}$) of not more than 12.0 minutes. Maximum corrective maintenance time ($M_{max\ ct}$) at the 95th percentile must not exceed 36.0 minutes.

The content of this example apportions these overall requirements to the multiplexer and demultiplexer level, thereby providing design objectives specifically related to each.

Attainment of the 2200-hour MTBF constraint requires an overall failure rate of not more than 455 failures per 10^6 hours. Differences in design implementation and complexity between the multiplexer and demultiplexer have been considered in the apportionment of this allowable failure rate to the two units. Resulting apportioned values are as follows:

Multiplexer - 150 failures/10^6 hours.
Demultiplexer - 305 failures/10^6 hours.

Allocation of overall maintenance time constraints was made on the basis of expected failure rate distribution and estimated maintenance times for the multiplexer and demultiplexer units. Values assigned to each unit are as follows:

Multiplexer - $\overline{M}_{ct}$ of 11.2 minutes; $M_{max\ ct}$ of 33.6 minutes
Demultiplexer - $\overline{M}_{ct}$ of 12.6 minutes; $M_{max\ ct}$ of 37.8 minutes

An estimate of mean corrective maintenance time for each unit, used in the allocation process, indicates a design potential well within the specified constraints.

Reliability and maintainability assessment and analysis effort during subsequent Multiplexer Set development phases will further evaluate the evolving design in terms of attaining apportioned constraints.

DESIGN NOTE 5B2 MAINTENANCE TIME ALLOCATION

1. GENERAL

Maintenance downtime requirements specified for the Multiplexer Set are as follows:

$\bar{M}_{ct}$ of 12.0 minutes

$M_{max\ ct}$ of 36.0 minutes at 95th percentile

These requirements have been allocated to the multiplexer and demultiplexer level. Methodology used in the allocation process is in accordance with the Maintainability Program Plan. See Chapter 3, DN 3D2.

The selected allocation process uses input data in two forms. (1) an estimate of mean maintenance downtime associated with one unit (multiplexer or demultiplexer) relative to the other and (2) distribution of total failure rate between the units.

These data are then used in solving equation (1) for x:

$$(x)\frac{fc_m}{100} + (K)\ (x)\ \frac{fc_d}{100} = 12.0$$

where: fc_m = percentage of total failure rate apportioned to multiplexer unit.

fc_d = percentage of total failure rate apportioned to demultiplexer unit $(1 - fc_m)$.

K = estimated demultiplexer mean maintenance time divided by estimated multiplexer mean maintenance time.

The resulting value for x is the allocated $\bar{M}_{ct}$ for the multiplexer unit, and the value Kx is the allocated $\bar{M}_{ct}$ for the demultiplexer unit.

2. MEAN MAINTENANCE TIME ESTIMATION

Estimates of mean maintenance times associated with the multiplexer and demultiplexer units were prepared using the following approach:

a. Preparation of functional flow diagrams depicting expected maintenance functions.

b. Assignment of times required in performing elemental tasks comprising these functions.

c. Computation of overall completion times for the various maintenance functions by summing the times required for their composite elemental tasks.

d. Combining maintenance function completion times on the basis of their expected occurrence probability.

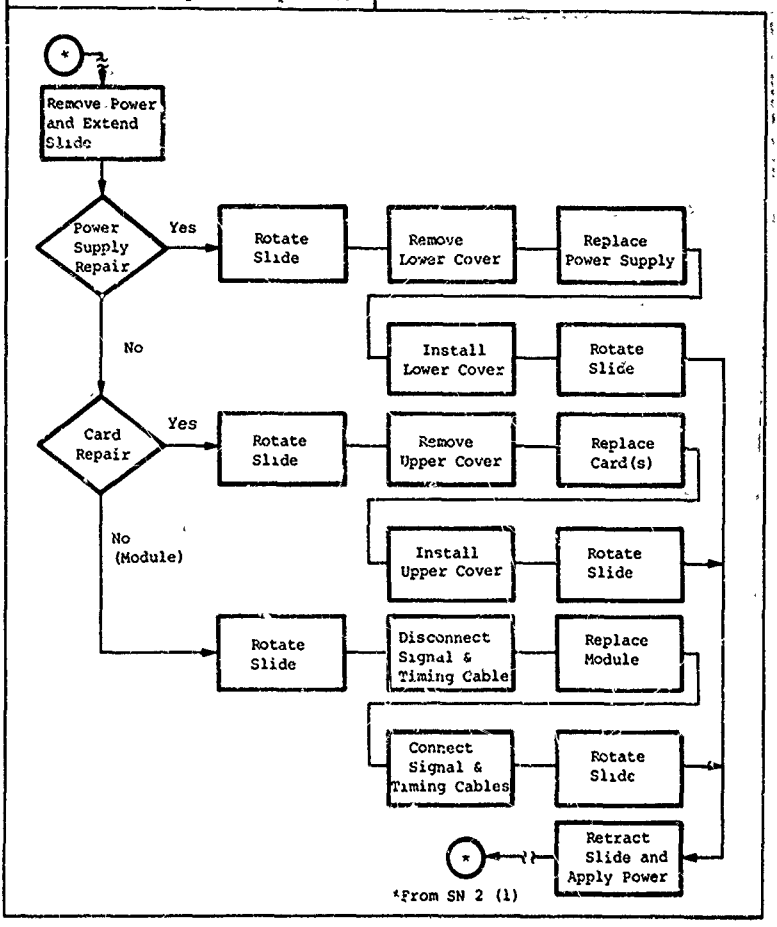
SN 2 (1) depicts the Multiplexer Set maintenance function in flow diagram format. Repair routines indicated in SN 2 (1) are expanded in SN 2 (2) for cases involving power supply, printed circuit card, and line driver/receiver replacement.

Estimated times for completing the various tasks depicted in SN 2 (1) and SN 2 (2) were then assigned. Summing these task times for the various expected maintenance functions yields the results shown in SN 2 (3).

It should be noted that times estimated for the functions listed in SN 2 (3) are applicable to both the multiplexer and demultiplexer units. This is due to the close similarity of fault isolation and packaging concepts and characteristics between the two. However, because of differences in circuit functions performed and the manner in which corresponding functions are implemented, complexity of the demultiplexer is somewhat greater than that of the multiplexer. This added complexity is reflected in the use of additional card-mounted integrated circuits, and therefore has an effect upon overall failure rate distribution between the multiplexer and demultiplexer units, as well as upon the distribution within each unit.

SUB-NOTE 2 (1) Simplified Maintenance Flow
Error Detector
Note Panel Indication
Perform Retest
An Error Remains
Yes
to
Transient
Error Is Same
Yes
No
Power Supply
No
Yes
Power Supply Repair*
Common Equipment
Yes
No
Establish Channel No.
RCB/SB
Yes
No
Card Repair*
RCVR/Driver Repair*
Error Remains
No
Yes
Manual Isolation
Return To Operation
* See SN 2 (2) for repair process flow.

SUB-NOTE 2 (2) Simplified Repair Flow



SUB-NOTE 2 (3) Maintenance Function Time Estimates

	Maintenance Function	Estimated Time (min)
1.	Card, Common Electronics	6.4
2.	Card, RCB/SB	6.5
3.	Card, Diagnostics	6.6
4.	Module, Line Driver/Receiver	6.7
5.	Power Supply	12.4
6.	Panel Lamps	2.3
7.	Other Items	45.0

The maintenance failure rate distribution within the multiplexer and demultiplexer units is shown in SN 2 (4). While this distribution has as a basis the failure rate prediction, certain modifications to this prediction have been made to enable estimation of the Multiplexer Set maintenance time.

From a reliability standpoint, power supplies within the multiplexer or demultiplexer unit are configured in a redundant arrangement with an automatic switchover capability in the event of failure. From a maintenance standpoint, however, a failure in either of the redundant supplies necessitates corrective maintenance.

Front panel lamps represent another area in which reliability and maintainability considerations differ. The random failure rate associated with the Multiplexer Set panel lamps is expected to be insignificant. However, lamp replacement rate due to end of life will be a relatively frequent occurrence. Thus, lamp replacement time is a contributor to maintenance time although it does not occur on a truly random basis. A similar situation is expected in the area of cooling air blowers. While not as significant as front panel lamps, there is a difference between replacement rate due to wearout and random failure rate. Again, maintenance time calculations should consider overall replacement rate, regardless of the phenomena prompting it. The maintenance failure rate distribution (percentage contributions) depicted in SN 2 (4)

is therefore based upon a summation of random failure rate and replacement rate caused by wearout or end of life.

SUB-NOTE 2 (4) Failure Rate Distribution (Percent)

	Percent Failures/ Unit	Percent Failures/ Total
Multiplexer		
1. Card, Common Electronics	4.3	2.0
2. Card, RCB/STRC	27.1	12.7
3. Card, Diagnostics	7.0	3.3
4. Module, Receiver/Driver	4.5	2.1
5. Power Supply	3.4	1.6
6. Panel Lamps	51.6	24.2
7. Other Items	2.1	1.0
	100.0	46.9
Demultiplexer		
1. Card, Common Electronics	8.6	4.6
2. Card, SB/TSRC	32.0	17.0
3. Card, Diagnostics	9.3	4.9
4. Module, Driver/Receiver	14.3	7.6
5. Power Supply	3.8	2.0
6. Panel Lamps	30.5	16.2
7. Other Items	1.5	0.8
	100.0	53.1
		Σ 100.0

SN 2 (5) reflects the combining of maintenance function time estimates of SN 2 (3) based upon the failure rate distribution of SN 2 (4). From SN 2 (5), it can be seen that the estimated mean corrective maintenance times for the multiplexer and demultiplexer units are as follows:

Multiplexer - 5.36 minutes

Demultiplexer - 6.05 minutes

SUB-NOTE 2 (5) Estimated Maintenance Time Computation

	(a) Percent of Failures	(b) Estimated Task Time	$\frac{(a)\ (b)}{100}$
Multiplexer			
1. Card, Common Electronics	4.3	6.4	0.28
2. Card, RCB/STRC	27.1	6.5	1.76
3. Card, Diagnostics	7.0	6.6	0.46
4. Module, Receiver/Driver	4.5	6.7	0.30
5. Power Supply	3.4	12.4	0.42
6. Panel Lamps	51.6	2.3	1.19
7. Other Items	2.1	45.0	0.95
	$\sum$ (a) = 100.0		$\sum \frac{(a)\ (b)}{100}$ = 5.36
Demultiplexer			
1. Card, Common Electronics	8.6	6.4	0.55
2. Card, SB/TSRC	32.0	6.5	2.08
3. Card, Diagnostics	9.3	6.6	0.61
4. Module, Driver/Receiver	14.3	6.7	0.96
5. Power Supply	3.8	12.4	0.47
6. Panel Lamps	30.5	2.3	0.70
7. Other Items	1.5	45.0	0.68
	$\sum$ (a) = 100.0		$\sum \frac{(a)\ (b)}{100}$ = 6.05

3. MEAN MAINTENANCE TIME ALLOCATION

Dividing the demultiplexer maintenance time estimate by that for the multiplexer yields a K value of 1.128 for use in solving equation (1) for x. Also required are the percentage failure contributions for individual units to the overall failure rate. This data is taken from the failure rate distribution shown in SN 2 (4) and are as follows:

Multiplexer contribution (fc_m) - 46.9
Demultiplexer contribution (fc_d) - 53.1
100.0

Substituting and solving equation (1) for x:

$$(x)\ \frac{fc_m}{100} + (Kx)\ \frac{fc_d}{100} = 12.0 \text{ minutes}$$

$$(x)\ (0.469) + (1.128)\ (x)\ (0.531) = 12.0 \text{ minutes}$$

$$x = 11.2 \text{ minutes}$$

Therefore, the mean corrective maintenance time allocated to the multiplexer is x or 11.2 minutes. The corresponding value allocated to the demultiplexer is Kx or 12.6 minutes.

4. MAXIMUM MAINTENANCE TIME ALLOCATION

Allocation of the Multiplexer Set maximum corrective maintenance time ($M_{max\ ct}$) requirement of 36.0 minutes is predicated upon maintaining the 1:3 ratio (12 minutes: 36 minutes) between the overall mean and maximum maintenance time requirements. Thus, the allocated $M_{max\ ct}$ for the multiplexer and demultiplexer units is simply three times the allocated mean or:

Multiplexer $M_{max\ ct}$ - 33.6 minutes
Demultiplexer $M_{max\ ct}$ - 37.8 minutes

5. SUMMARY OF ALLOCATED MAINTENANCE TIMES

SN5 (1) summarizes the allocated $\overline{M}_{ct}$ and $M_{max\ c.}$ values for the multiplexer and demultiplexer units.

SUB-NOTE 5 (1) Summary of Allocated Maintenance Times

UNIT	ALLOCATED $\overline{M}_{ct}$ *	ALLOCATED $M_{max\ ct}$
Multiplexer	11.2	33.6
Demultiplexer	12.6	37.8

(*) All times in minutes.

CHAPTER 6

MAINTAINABILITY REPORTS

This chapter contains a detailed task description of the maintainability reports identifying the documentation requirements and presenting examples of reports relative to the Multiplexer Set.

CHAPTER 6 MAINTAINABILITY REPORTS

SECTION 6A - MAINTAINABILITY REPORTS INTRODUCTION

Design Note 6A1 - Detailed Task Description

6A2 - Documentation Requirements

SECTION 6B - MULTIPLEXER SET EXAMPLE MAINTAINABILITY REPORTS

Design Note 6B1 - Multiplexer Set Combined Examples of Reliability and Maintainability Reports

SECTION 6A

MAINTAINABILITY REPORTS INTRODUCTION

This section contains a task description and documentation requirements for maintainability reports.

SECTION 6A MAINTAINABILITY REPORTS INTRODUCTION

DESIGN NOTE 6A1 - DETAILED TASK DESCRIPTION

1. GENERAL

2. PROGRESS REPORTING METHODS

DESIGN NOTE 6A2 - DOCUMENTATION REQUIREMENTS

1. GENERAL

1 (1) Reliability/Maintainability Program Status Reports

1 (2) Reliability and Maintainability Allocations, Assessments, and Analysis Report

DESIGN NOTE 6A1 DETAILED TASK DESCRIPTION

1. GENERAL

The primary purpose of the maintainability report is simple: it is to provide a current accounting of the maintainability program progress. The interval of report periodicity is usually contained in the contract data requirement list (CDRL) as a part of the RFP and, eventually, the contract. The periodicity of these reports may vary from monthly to midcontract and final. Most often, the contract stipulates a quarterly report.

The report content may vary, as well as the periodicity. There are summary reports that may be considered adequate, and there are detailed reports that include narrative and graphical treatment of trends, problems encountered or anticipated, and action taken or proposed.

2. PROGRESS REPORTING METHODS

There are several methods of making a periodic progress report, and most require some sort of agreement between the customer/contractor. Latitude for these various reporting techniques is provided in MIL-STD-470, which states "these reports may be combined with other program documentation." Some of the current progress report methods include reliability/maintainability program status reports and the reliability/maintainability allocations, assessments, and analysis report.

The data item description for these methods is covered in DN 6A2. Examples of these reports are included in Section 6B.

DESIGN NOTE 6A2 DOCUMENTATION REQUIREMENTS

1. GENERAL

The data item for maintainability reports are described in SN 1 (1) and SN 1 (2). These sub-notes are the data item descriptions that would be listed in the Contract Data Requirement List (CDRL) on contra t form DD-1423 when the item is required by contract.

SUB-NOTE 1 (1) (Sheet 1 of 2 sheets) Data Item Description

DATA ITEM DESCRIPTION

2. IDENTIFICATION NO(S).: AGENCY: USAF; NUMBER: DI-R-3542/R-110-2

1. TITLE: Reliability/Maintainability Program Status Reports

3. DESCRIPTION/PURPOSE: To monitor and evaluate contractor's progress and accomplishments in conducting the Reliability/Maintainability Program for the applicable configuration item(s).

4. APPROVAL DATE: 21 May 1971

5. OFFICE OF PRIMARY RESPONSIBILITY: AFSC

6. DDC REQUIRED:

8. APPROVAL LIMITATION:

7. APPLICATION/INTERRELATIONSHIP: Applicable to contracts which contain the requirement for a Reliability/Maintainability Program.

9. REFERENCES (Mandatory as cited in Block 10): MIL-STD-470, MIL-STD-471, MIL-STD-721, MIL-STD-781, MIL-STD-785

MCSL NUMBER:

10. PREPARATION INSTRUCTIONS

1. Each report shall include the following information as a minimum:

a. The work accomplished and results obtained on each task defined by the work statement or the Contractor's Reliability/Maintainability Program Plan.

b. Summaries of the status of previously reported problems which were unresolved at the close of the last reporting period.

c. A list of current problems containing:

(1) A serial number assigned to identify the problem.
(2) The date on which the problem was first detected.
(3) A short statement identifying the problem and its effect.
(4) The persons and the activity assigned to work on the problem.
(5) The expected resolution date.
(6) A short statement of accomplishment to-date or a cross-reference to other reports.
(7) The date the problem was resolved.

NOTE: A problem may be dropped from the list after reporting resolution.

d. A specific accounting of each design review action item remaining open at the end of the last report period including a full description of the action taken on each item.

e. A summary of all major characteristics departures recorded during the report period, indicating defective characteristics, extent of deviation from acceptable limits, and action taken.

f. Identification of observed potential reliability/maintainability problems introduced by Government-furnished and associate-contractor-supplied elements, and

DD FORM 1 JUN 68 1664 PAGE 1 OF 2 PAGES

SUB-NOTE 1 (1) (Sheet 2 of 2 sheets) Data Item Description

descriptions of accommodations or improvement changes deemed necessary to make such elements compatible.

g. A summary of the results of quality audit actions conducted during the period, including corrective action status of all new and previously unresolved problems.

h. A discussion of the currently observed and predicted potential reliability for the contract item. The established reliability requirements will be included for comparison.

2. The report shall include a graphic discussion of trends. A breakdown to the configuration item level shall be made in the following manner:

Minimum Acceptable Requirements	Allocated	Predicted	Observed values (e.g., lower confidence level, mean, max, procedures, consumer risks, etc.)

3. The report shall include proposed changes to the Reliability/Maintainability Program Plan (as applicable).

4. The final reliability/maintainability progress report shall be a summary-type "technical report" indicating the major reliability/maintainability events in the program and results achieved.

SUB-NOTE 1 (2) (Sheet 1 of 2 sheets) Data Item Description

DATA ITEM DESCRIPTION	2 IDENTIFICATION NOS: AGENCY	NUMBER
1 TITLE: Reliability and Maintainability Allocations, Assessments, and Analysis Report	USAF	DI-R-3535/ R-103-2
3 DESCRIPTION/USE: This report is used to (1) evaluate the contractor's estimate of reliability and maintainability (the predicted growth, allocation, and degree of achievement of these characteristics in the configuration item and its constituent elements); (2) evaluate the current and potential reliability and maintainability of the configuration item design; (3) provide information to assist in directing and planning for reliability and maintainability and related program efforts; and (4) identify design features which are critical to reliability and maintainability.	4 APPROVAL DATE: 21 May 1971	
	5 OFFICE OF PRIMARY RESPONSIBILITY: AFSC	
	6 DOC REQUIRED	
	8 APPROVAL LIMITATION	
7 APPLICATION/INTERRELATIONSHIP: This Data Item Description is applicable to system development during the contract validation and full scale development phases and equipment development contracts for complex equipments through the end of category II tests. It may be applied to appropriate conceptual phase studies, exploratory, and advanced equipment developments. It may also be used to define information to be submitted in response to a request for proposal.	9 REFERENCES (Mandatory as cited in block 10): MIL-STD-470, MIL-STD-721, MIL-STD-756, MIL-STD-785, MIL-HDBK-217, MIL-HDBK-472, MIL-STD-499	
	MCSL NUMBER(S):	

10 PREPARATION INSTRUCTIONS

1. This report shall contain, as a minimum, the following information:

a. Contractor's analysis of reliability and maintainability potential of the configuration item design, including mathematical models, logic diagrams, functional block diagrams, assumed operating conditions, environmental criteria, and other considerations used in the calculations (i.e., combining data and confidence limits when multiple tests are conducted).

b. Equipment breakdown to the lowest practical level of indenture with associated reliability and maintainability parameters.

c. Analysis of potential modes of failures; their probable cause and effects on performance, reliability, and maintainability. The severity of these effects and the probability of occurrence under applicable operating modes and environments shall be indicated. Definitions of failure must include those expected to be used by maintenance personnel and operators.

d. Description of the purpose and function of applicable items.

e. A description of trade studies involving reliability, maintainability, and other factors and the resulting effects on overall system effectiveness. Trade studies shall be made available at the request of the procuring activity to substantiate/expand results.

f. Effects of storage, shelf-life, packaging, transportation, handling, and

SUB-NOTE 1 (2) (Sheet 2 of 2 sheets) Data Item Description

DI-R-3535/R-103-2 (Continued)

Preparation Instructions (Continued)

maintenance on the product reliability. Major or critical characteristics of items which deteriorate with age should be included, plus environmental limits, maintenance philosophy, equipment usage, etc.

g. The contractor's conclusions, identification of problem areas, related actions taken or proposed, and a list of further design studies planned as a result of these analyses.

h. The contractor's allocations of the overall quantitative goals and minimum requirements for configuration item reliability and maintainability as specified by the procuring activity or developed by the contractor. As a general rule, this breakdown should be carried to the level at which failure reports will be submitted.

i. Current observed achievement of reliability or maintainability of the configuration item and its constituent elements to the lowest practical level of indenture. In each case, the type and units of measurement shall be clearly identified (e.g., the distribution of TBF, CBF, TTR active time, TTR man-hours, availability, probability of satisfactory performance, percent successful, etc.). Confidence levels or intervals shall be stated where appropriate. Achieved and predicted reliability growth curves shall be included. A comparison with the analysis and allocation for the configuration item shall be included.

Note: TBF - Times Between Failures

CBF - Cycles Between Failures

TTR - Times to Repair

SECTION 6B

MULTIPLEXER SET EXAMPLE MAINTAINABILITY REPORTS

This section contains an example of the reliability and maintainability reports relative to the Multiplexer Set. It is a combination of the program status report and the allocations, assessments, and analysis report. For this example, the reliability data is intentionally omitted.

DESIGN NOTE 6B1 — MULTIPLEXER SET COMBINED EXAMPLES OF RELIABILITY AND MAINTAINABILITY REPORTS

1. INTRODUCTION

1 (1) Cover Page

1 (2) Preface

1 (3) Table of Contents

1 (4) Part I - Reliability Program Status Report Outline

1 (5) Part II - Maintainability Program Status Report

1 (6) Part III - Reliability and Maintainability Allocation, Assessment, and Analysis Report, Revision 7

1 (7) Part V - Program Discussion

DESIGN NOTE 6B1

MULTIPLEXER SET COMBINED EXAMPLES OF MAINTAINABILITY REPORTS

1. INTRODUCTION

This design note contains an example of a combined reliability and maintainability report on the multiplexer set. Examples of the contents in each section of these reports are contained in SN 1 (1) through SN 1 (7). The reliability data is intentionally omitted unless pertinent to the maintainability report.

SUB-NOTE 1 (1) Cover Page

CER-RM-003-6

Reliability Program Status Report:
Maintainability Program Status Report;
Reliability and Maintainability Allocation,
Assessment, and Analysis Report (Revision 7);
Failure Summary Report

For

Multiplexer Set AN/GSC-24(V)
Contract: F30602-70-C-0143 29 February 1972

SUB-NOTE 1 (2) Preface

This document contains four reports covering the reliability and maintainability program for Multiplexer Set AN/GSC-24(V).
Part I contains the seventh Reliability Program Status Report.
Part II contains the seventh Maintainability Program Status Report
Part III contains the seventh revision to the Reliability and Maintainability Allocation, Assessment, and Analysis Report (RMAAA).
Part IV contains the seventh Failure Summary Report.

SUB-NOTE 1 (3) Table of Contents

Preface

Table of Contents

Part I: Reliability Program Status Report*

1.0 Introduction

2.0 Task Summary

3.0 Problem Summary

4.0 Critical and Major Characteristic Departure

5.0 Quality Audit Actions

6.0 GFE Reliability Problems

7.0 Current Reliability

Part II: Maintainability Program Status Report

1.0 General

2.0 Current Predictions

3.0 Maintenance Related Data

4.0 Plans for Next Period

Part III: Reliability and Maintainability Allocation, Assessment, and Analysis Report, Revision 6

1.0 Introduction

2.0 Equipment Description

3.0 Reliability Analysis*

4.0 Maintainability Analyses

Part IV: Failure Summary Report*

Part V: Program Discussion

Appendix I PREFERRED PARTS LIST*

Appendix II RESUME*

Appendix III BEAM LEAD HYBRID ANALYSIS*

Appendix IV POWER SUPPLY PREDICTION WORKSHEETS*

References*

*This item intentionally omitted from this example.

SUB-NOTE 1 (4) (Sheet 1 of 2 sheets) Reliability Program Status Report Outline (CLIN B032 and R-110-2)

1.0 Introduction

This part contains the seventh Reliability Program status report covering the period 16 November 1971 through 15 February 1972. It contains an accounting of work done and results obtained on each task defined by the work statement of the program plan. Up-to-date summary discussions of current and future status is provided and a current list of problems are included.

2.0 Task Summary

This report is an update of the Reliability Program Plan, reference 1, dated 14 August 1970. Figure I-1 presents the updated milestone chart.

2.1 Reliability Apportionment

2.2 Design Reliability Prediction

2.3 Design Reviews

2.4 Reliability Program Reviews

2.5 Parts Control

2.6 Data Collection, Failure Analysis, Corrective Action

3.0 Problem Summary

4.0 Critical and Major Characteristic Departure

5.0 Quality Audit Actions

6.0 GFE Reliability Problems

7.0 Current Reliability

SUB-NOTE 1 (1) (Sheet 2 of 3 sheets) Reliability Program Status Report Outline (CLIN 0002 and P-110-2)

Figure 1-1 Multiplexer Set Reliability and Maintainability Milestones

MASTERPLAN

DESCRIPTION	1971 A M J J A S O N D	1972 J F M A M J J A S O N D	1973 J F M A M J J A S
ATM System Design			
Advanced Development Model (list of 8 sets)			
Procurement of Materials			
Fabrication and Assembly			
Test			
Prototype Multiplexer Sets (8 sets total)			
Procurement of Materials			
Fabrication and Assembly			
Test and Evaluation			
Delivery			
Reliability Program Tasks			
Reliability Program Plan	▲		
Reliability Apportionment	▲		
Design Reliability Prediction			
Intermediate Prediction			
Design Prediction			
Design Reviews			
Preliminary Design Review (PDR)			
Critical Design Review (CDR)			
Parts Control			
Parts Specification Submittal			
Reliability Tests and Evaluation			
Reliability Demonstration Plan		▲	
Reliability Demonstration			
Reliability Test and Evaluation Report			
Data collection, failure, analysis, corr. action			
Reliability Program Reviews			
Reliability Progress Reports	▲ ▲ ▲

SUB-NOTE 1 (5) Part II - Maintainability Program Status Report

1.0 General

Laboratory testing of the first Multiplexer Set prototype, initiated last reporting period, continues. Functional performance of integral diagnostic circuits has been demonstrated for both the multiplexer and demultiplexer chassis.

Several minor problems having maintenance impact were discovered, investigated, and resolved during this reporting period. These are discussed in Part III.

2.0 Current Predictions

Currently predicted maintenance times are as follows:

	Required	Predicted
a. $\overline{M}_{ct}$	12.0 minutes	6.32 minutes
b. $M_{max\ ct}$	36.0 minutes	16.40 minutes

The above predicted values remain unchanged from those previously reported.

3.0 Maintenance Related Data

RADC comments relative to the Multiplexer Set Maintainability Demonstration Plan were received this period. The contents of these comments are currently being reviewed before initiation of plan revision.

Submittal of revised AGERD, previously planned for this reporting period, will be made upon completion of card and module test set cost estimates.

4.0 Plans for Next Period

Plans for the next reporting period include the following:

a. Submittal of revised AGERD

b. Continuation of Calibration Requirement Summary (CRS) preparation

c. Revision of Maintainability Demonstration Plan.

d. Initiation of maintainability demonstration task sample selection.

SUB-NOTE 1 (5) (Sheet 1 of 5 sheets) Part III - Reliability and Maintainability Allocation, Assessment, and Analysis Report, Revision 7

1.0 Introduction

This seventh revision updates data submitted in earlier reports and documents additional analyses.*

2.0 Equipment Description

2.1 General

The Multiplexer Set is applied in the Defense Communications System (DCS) for combining digital channels into a single, time division multiplexed, digital data signal. The first application of the Multiplexer Set is expected to be in the Phase II Defense Satellite Communications System (DSCS Phase II). Satellite access and short-haul, high-density applications also will involve TDM transmission over wideband ground links. The wide variety of data rates which must be accommodated to service the many DCS users properly results in a wide range of the number of channel inputs to a multiplexer; it further requires the capability to cascade multiplexer sets to reach high data rates for efficient link loading.

2.2 Operating Functions

The Multiplexer Set provides asynchronous time division multiplexing and demultiplexing capabilities. The multiplexer portion accepts various lower rate digital input streams and interleaves them into a single higher speed digital stream. The demultiplexer portion accepts a high speed digital stream, with associated timing, and disassembles it into a number of lower rate digital streams. The Multiplexer Set provides full duplex operation, performing independently and simultaneously the multiplexer and demultiplexer functions.

The Multiplexer Set acquires frame and maintains bit count integrity on all channels while accepting input data timing variations within prescribed limits. The Multiplexer Set automatically determines where an out-of-frame condition exists. Upon determination of this condition, the equipment automatically and continuously attempts to reacquire inframe condition. When the cause for out-of-frame condition has been removed, the reacquisition of in-frame condition is automatically accomplished.

* This example does not include the reliability data normally part of a combined report.

SUB-NOTE 1 (6) (Sheet 2 of 5 sheets) Part III - Reliability and Maintainability Allocation, Assessment, and Analysis Report, Revision 7

The multiplexer automatically generates and transmits, as part of the composite multiplexer output data stream, the overhead data required for proper operation of the demultiplexer. The multiplexer does not require information from the demultiplexer to perform the overhead data function. The demultiplexer receives and automatically detects and utilizes the overhead data for proper operation of the demultiplexer.

2.3 Packaging Characteristics

The Multiplexer Set is housed in two dip brazed aluminum drawers, one for the multiplexer and another for the demultiplexer. These drawers measure approximately 26-7/32 inches high for a total height of about 52-7/16 inches. The 17-1/4-inch width makes the equipment suitable for standard relay rack mounting. Chassis slides are mounted on each side of the drawers. When the drawers are pulled out, they may be tilted $\pm 45°$ and $\pm 90°$.

All operator controls and indicators are mounted on a front panel. Wires from the front panel components are routed to the internal electronics through connectors which are mounted in a secondary panel directly behind the front panel.

The electronic circuits are mounted on edge-loaded cards which, in turn, are mounted in a wiring plane. A total of 31 card types are used in the Multiplexer Set. Of these, nine types are common to both the multiplexer and demultiplexer units. Table III-1 is a listing of card types by name and unit application.

The multiplexer rate comparison buffer card (RCB) may be replaced by a source rate to transmission rate converter card (STRC) or a transition encoder card (TE). The demultiplexer smoothing buffer card (SB) may be replaced by a transmission rate to source rate converter card (TSRC) or a transition decoder card (TD).

Line driver and line receiver circuits are assembled into enclosed, RFI sealed metallic modules. Each module contains two line receiver circuits or two line driver circuits. Thirty-three modules are mounted on the back of the multiplexer and 32 on the demultiplexer drawers. On the multiplexer, 31 of the modules are line receiver modules (total of 62 line receiver circuits) and one is a high-speed line receiver used in conjunction with external timing input, and one is a line driver module (total of two line driver circuits).

SUB-NOTE 1 (6) (Sheet 3 of 5 sheets) Part III - Reliability and Maintainability Allocation, Assessment, and Analysis Report, Revision 7

TABLE III-1

Multiplexer Set Printed Circuit Cards

	Name	Used In
1)	Power Supply Monitor	Mux/Demux
2)	Mux Lamp Driver	Mux
3)	Overhead Enable Generator	Mux/Demux
4)	Strapping Switches	Mux/Demux
5)	Port Sequencer	Mux/Demux
6)	Sequencer Diagnostics	Mux/Demux
7)	Channel Sequencer	Mux/Demux
8)	Gates Clocks	Mux/Demux
9)	Reference Timer	Mux
10)	Data Multiplexer	Mux
11)	Oscillator Carrier	Demux
12)	Distributor Matrix	Demux
13)	Divide-by-n Counter No. 1	Demux
14)	Divide-by-n Counter No. 2	Demux
15)	Synthesizer Distributor	Demux
16)	Frame Sync	Demux
17)	Variable Length Shift Register	Demux
18)	Channel Monitor	Mux/Demux
19)	On-Line Maintenance	Mux/Demux
20)	Mux Remote Alarm	Mux
21)	Frequency Synthesizer	Demux
22)	Demux Lamp Driver	Demux
23)	Demux Remote Alarm	Demux
24)	Rate Comparison Buffer (RCB)	Mux
25)	Source to Transmission Rate Converter (STRC)	Mux
26)	Transition Encoder (TE)	Mux
27)	Smoothing Buffer High Speed (SBHS)	Demux
28)	Smoothing Buffer Low Speed (SBLS)	Demux
29)	Transmission to Source Rate Converter (TSRC), High Speed	Demux
30)	TSRC Low Speed	Demux
31)	Transition Decoder	Demux

SUB-NOTE 1 (6) (Sheet 4 of 5 sheets) Part III - Reliability and Maintainability Allocation, Assessment, and Analysis Report, Revision 7

On the demultiplexer, 31 of the modules are line driver modules (total of 62 line driver circuits) and one is a line receiver module (total of two line receiver circuits). The wires from the modules are routed into the chassis through EMI filters.

The multiplexer and demultiplexer both contain dual power supplies. Power distribution between power supplies, wiring plane, and modules is by means of laminated bus bars.

Each multiplexer and demultiplexer chassis incorporates a cooling blower located on the upper rear surface. These blowers draw air from the front of the equipment, and from the rear of the equipment via the line driver and receiver module area. Cooling air entering the drawer internals is routed through filters located at the top and bottom of the chassis front panel.

3.0 Reliability Analysis (This paragraph intentionally omitted.)

4.0 Maintainability Analysis

4.1 Maintenance Time Predictions

Predicted Multiplexer Set maintenance times remain unchanged from those reported in Revision 5. M_{ct} and $M_{max\ ct}$ values are 6.32 and 16.40 minutes respectively, and are significantly below the specified requirements.

During this reporting period, selected maintenance tasks were performed, using Multiplexer Set prototype 1. The purpose of this effort was to obtain a spot check comparison between predicted and observed times for frequently performed tasks or task elements. Results of this effort indicate a reasonably good correlation between predicted and observed times, with most observed task times being lower than those predicted. Dependent upon hardware availability, further such spot checking will be performed during the next reporting period.

4.2 Laboratory Assessment

As a result of laboratory assessment efforts this period, three design problems having maintenance impact were observed. All have been corrected via design revision. The following paragraphs briefly describe these problems and their solutions.

SUB-NOTE 1 (6) (Sheet 5 of 5 sheets) Part III - Reliability and Maintainability Allocation, Assessment, and Analysis Report, Revision 7

4.2.1 Power Filter Replacement

A mechanical interference problem between the chassis structure and the harness connecting to the equipment side of the input filter assemblies was observed. This interference precluded filter replacement from the rear of the chassis, thus requiring wiring plane removal as part of the filter replacement process. This problem was resolved by enlargement of the chassis clearance holes through which the filter wiring harness is routed. With this change, either of the filter assemblies may be extended a sufficient distance from the chassis rear surface to permit separation or connection of the filter electrical terminals.

This revision has been incorporated in the Multiplexer Set prototypes, and has been demonstrated to have corrected the problem.

4.2.2 Excessive Cable Flexure

Routing of the chassis wiring harness between the input power filter assemblies and the front panel assembly was observed to be causing excessive short radius harness flexure at the front door interface. To correct this problem, the wiring harness has been lengthened and clamped to cause flexure over its entire length. Laboratory testing has shown this to be an acceptable solution, and the problem is considered resolved.

4.2.3 Power Supply Replacement

Positive 5-volt and 5-volt return outputs of the Multiplexer Set power supplies interface with chassis distribution buses via heavy gauge jumper straps. Routing of these straps in the No. 1 prototype chassis was observed to be causing unacceptable interference between the straps and the power supply assemblies. Also, shortness of the straps combined with the thickness of strap material made physical interconnection with the supply output terminals extremely difficult.

This problem has been resolved by a lengthening and rerouting of the interconnection straps. Laboratory trials with this design revision have demonstrated that power supply replacement can now be accomplished without abnormal difficulty.

SUB-NOTE 1 (7) (Sheet 1 of 2 sheets) Part V - Program Discussion

1.0 Program Discussions

This section summarizes general discussions that have taken place between the Multiplexer Set customer and contractor.

2.0 Program Review at RADC - December 15-17, 1971

The minutes of this meeting have been published under contractor letter number 72-3C041, dated 11 January 1972.

3.0 Customer Visits

Captain (_____) of RADC visited the contractor facility on January 27 and 28. Replacing Captain (_____) as the RADC reliability and maintainability specialist, Captain (_____) was briefed on the overall Multiplexer Set design effort. Particular attention was given to the reliability and maintenance related design details and features.

A general discussion of the forthcoming maintainability demonstration was held. It was agreed that increased RADC/contractor coordination and liaison would be instituted as demonstration planning firms.

A general discussion of the forthcoming environmental and reliability demonstration tests was held, in addition to a review of the total Multiplier Set reliability effort. Ground rules for revising previous RMAAA reports were established. It was agreed that these revisions would be incorporated in this report rather than reissuing the old reports.

On February 4, 1972, Mr. (_____) visited the contractor facility Mr. (_____) requested that the failure rates on the Multiplexer Set cards be provided for three levels of part classifications. These were provided to Mr. (_____) in a letter communication on February 9, 1972.

4.0 Telephone Communication

On February 14, 1972, Mr. (_____) called Captain (_____) and requested that RADC consider relieving the salt fog requirement in the environmental test plan. Since the environmental unit is scheduled for GFE tests at ETR, it is felt the salt fog test will be nonbeneficial to the ETR objectives. The Multiplexer Set by design will not prevent salt cake from totally permeating the unit to such an extent it will virtually be impossible to clean the unit,

SUB-NOTE 1 (7) (Sheet 2 of 2 sheets) Part V - Program Discussion

and in particular the wiring plane. This will inhibit long term service testing by the Air Force. Captain (_____) agreed to investigate the benefit of this test to the Multiplexer Set program and advise.

5.0 General

Due to the revision of the test quantities in the reliability demonstration tests, the demonstration test plan is being revised. This revision will be completed by March 30, 1972.

CHAPTER 7

TRADE-OFFS

This chapter contains a description of the maintainability trade-off task, with guidelines, methodology, and procedures. An example of a discard versus repair trade-off is included for the Multiplexer Set. The last section contains data related to the cost of designing in varying degrees of maintainability.

CHAPTER 7 TRADE-OFFS

SECTION 7A - MAINTAINABILITY TRADE-OFF TASK DESCRIPTION

Design Note 7A1 - Detailed Task Description

7A2 - Trade-Off Processes

SECTION 7B - MAINTAINABILITY TRADE-OFF GUIDELINES AND METHODOLOGY

Design Note 7B1 - Guidelines and Methodology

SECTION 7C - MAINTAINABILITY TRADE-OFF PROCEDURES

Design Note 7C1 - General Trade-Off Procedures

7C2 - Repair/Discard Trade-Off Procedure

SECTION 7D - MULTIPLEXER SET TRADE-OFF EXAMPLE

Design Note 7D1 - Discard versus Repair Cost Analysis for the Multiplexer Set Printed Circuit Cards and Modules

SECTION 7E - COST OF MAINTAINABILITY (to be inserted after correction)

Design Note 7E1 - Purpose, Scope, and Data Sources

7E2 - Cost of Maintainability Roots

SECTION 7A

MAINTAINABILITY TRADE-OFF TASK DESCRIPTION

This section contains a detailed task description of the maintainability trade-offs and the trade-off processes.

SECTION 7A MAINTAINABILITY TRADE-OFF TASK DESCRIPTION

DESIGN NOTE 7A1 - DETAILED TASK DESCRIPTION

1. GENERAL

DESIGN NOTE 7A2 - TRADE-OFF PROCESSES

1. TRADE-OFF CRITERIA

1 (1) System Cost Categories

1 (2) Typical Equipment Cost History

1 (3) Typical Display of Total Lifetime Cost vs Initial Cost

DESIGN NOTE 7A1 DETAILED TASK DESCRIPTION

1. GENERAL

A trade-off is defined as an analysis of competing system characteristics and factors to determine the optimum overall combination. Simply stated, it is a comparison of two or more ways of doing something for the purpose of making a decision. Trade-offs are conducted to some degree of complexity and detail in all phases of development of a system. The primary purpose of a maintainability trade-off is to enable selection of that system design and maintenance concept candidate which meets or exceeds the operational requirements at the minimum total system cost.*

The secondary objectives of trade-offs are to:

- Investigate the relative advantages of various concepts or configurations (sensitivity testing).
- Provide data and background for feasibility of a program.
- Provide a basic medium, with facts, by which decision can be made by management.
- Substantiate or refute a previous decision.

The trade-off must consider all the factors and not just present those advantageous to some prejudiced viewpoint. The incomplete tradeoff study can present shaded facts that will lead to decisions that will be detrimental in terms of life cycle cost when the system becomes operational.

Maintainability related trade-offs can be classified into three major categories:

- Design philosophy
- Maintainability design trades
- Maintenance support trades

*This assumes that the system contract is based on life cycle cost. If the contract is based on acquisition cost alone, then, in practice, the trade-off objective will be to select the design candidate which meets the operational requirements at the minimum acquisition cost.

in each case, the advantages and disadvantages in terms of effect on operational effectiveness and life cycle cost are considered. The most significant problem in conducting a trade-off is the acquisition of reliability, cost, maintenance time, and other data. This problem is extremely acute in early phases of equipment development. Reliability data is used to:

- Calculate the number of equipment failures, which is used as a basis for determining support requirements.
- Calculate the system/equipment $\overline{M}_{ct}$.
- Identify requirements for design considerations.

DESIGN NOTE 7A2 TRADE-OFF PROCESSES

1. TRADE-OFF CRITERIA

As in all system trade-offs, each candidate must meet or exceed the mission requirements and program constraints. Beyond that, costs are the basic selection criteria for trade-offs. The costs associated with each equipment design and maintenance concept alternative are computed, and the least costly alternative that provides the desired effectiveness is selected.

The costs associated with alternative equipments are composed of three major cost categories: research and development, acquisition or initial investment, and operation and support. The general costs contributing to the three categories are shown in SN 1 (1). These general cost categories correspond to the life cycle of a new piece of equipment - development, introduction, and operation.

SUB-NOTE 1 (1) System Cost Categories

Research and Development Costs

(1) System Development
- (a) Preliminary study and design
- (b) Design engineering
- (c) Hardware fabrication
- (d) Documentation

(2) System Test and Evaluation
- (a) Equipment fabrication
- (b) Test programs (including Reliability and Maintainability)
- (c) Test equipment
- (d) Facilities

(3) Other System and Development Costs
- (a) Maintenance and spares support
- (b) Miscellaneous

Initial Investment Costs

(1) Equipment
- (a) Initial Procurement
- (b) Spares and repair parts
- (c) Initial transportation
- (d) Installation

Initial Investment Costs (continued)

(2) Personnel
- (a) Increased manpower requirements
- (b) Initial training
- (c) Initial travel

(3) Facilities

(4) Miscellaneous Investment Costs

Operating Costs

(1) Equipment
- (a) Operation
- (b) Training allowance
- (c) Annual transportation
- (d) Maintenance
- (e) Spares

(2) Personnel
- (a) Pay and allowance
- (b) Training
- (c) Travel

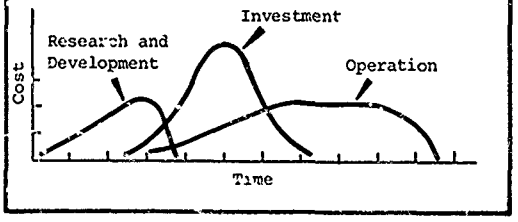
(3) Facilities

(4) Miscellaneous Operating Costs

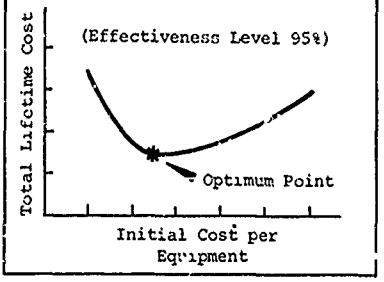
SN 1 (2) shows, in simplified form, the cost history of a typical equipment. The costs for each of the three major cost categories are represented by smoothed curves, typically displaying successive maximums.

It is significant that a long period of operation at relatively high cost will have a much greater impact on the total cost than either research and development or initial investment costs. This concept can be illustrated by plotting a curve of total lifetime cost versus initial cost per equipment for any desired effectiveness level of an equipment, as shown in SN 1 (3).

SUB-NOTE 1(2) Typical Equipment Cost History



SUB-NOTE 1(3) Typical Display of Total Lifetime Cost Vs Initial Cost



The optimum is the initial equipment cost that produces the lowest total life-time cost.

SECTION 7B

MAINTAINABILITY TRADE-OFF GUIDELINES AND METHODOLOGY

This section contains guidelines and methodology for accomplishing maintainability trade-offs, and also included a discussion of limiting case analysis.

DESIGN NOTE 7B1 GUIDELINES AND METHODOLOGY

1. TYPES OF TRADE-OFFS

Trade-offs related to maintainability can be divided into two types: exception trades and optimization trades. Exception trades are those which fall into the all or none category, in the sense that any deviation from all or none of the root will cause the maintenance cost to increase; for example, if the "none" principle is violated for adjustments, in that one is proposed to be incorporated in a design, then procedures and manpower must be furnished for maintenance created by the presence of the adjustment. They are termed exception trades because they only need be conducted when some deviation to the all or none principle is proposed in the design concept or design. Maintainability roots which fall into this category are as follows:

- None - Adjustment
- All - Packaging classification (functional)
- None - Preventive maintenance (including calibration)
- All - Packaging mounting (plug-in)
- All - Interchangeability
- None - Accessibility (stacking and multiturn, noncaptive fasteners)

Although AGE is not a maintainability root, it is a maintainability factor, and requirements for special tools fall in this same category (none).

An example of conducting an exception trade is adjustments. Each time an adjustment is proposed in a system, a trade should be conducted to determine if the cost to design the system without the adjustment results in greater or less cost than the change in maintenance cost incurred with the adjustment in the deployment phase.

Optimization trades are those which must be conducted on every program because there is no known answer or starting point for that maintainability root in terms of all or none, which results in the minimum maintenance cost.

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The maintainability roots which fall into this category are as follows:

- Standardization
- Packaging (structure)
- Fault location

The maintainability factor which falls into this category is the maintenance (and spares) concept.

The first order effects that the maintainability roots and factors have on the requirement for logistics resources is shown in SN 1 (1).

2. PRIME TRADE-OFF

In the conduct of maintainability trade-offs, there is one trade-off which should be considered as prime. This prime trade-off is called the repair/discard trade and results in the following decisions:

- The number of hardware levels, and the complexity of each.
- The discard-at-failure (DAF) level
- The type of diagnostics for each hardware level.
- The maintenance and spares concept for each hardware level.

This is an optimization trade-off. All other trades should be conducted after this one, using its results as the baseline design and support system.

As mentioned previously, each candidate should be analyzed to make sure that it satisfies the required maintainability indices, such as $\overline{M}_{ct}$, and any other required constraints related to maintainability.

3. TRADE-OFFS RELATED TO SYSTEM CHARACTERISTICS

To this point, the impact of maintainability design and maintenance concept on logistics resource requirements has been addressed.

In order to conduct trade-offs, however, some insight should be provided regarding the system characteristics which are fundamental in the relationships (or sensitivity) to maintainability roots. Also, the same insight must be provided regarding the relationships between the maintainability roots. These relationships are identified in SN 3 (1).

SUB-NOTE 1 (1) Potential Impact of Maintainability Roots and Factors on Logistics Resource Requirements (First Order)

	Logistics Resources						
	Technical Orders	Spares	Training	Personnel	Facilities	AGE	Transportation
Maintainability Roots							
Adjustments	X		X	X		X	X*
Calibration (PM)	X		X	X	X	X	X*
Accessibility	X			X		X	
Standardization		X	X			X	
Interchangeability	X	X	X	X			X*
Packaging Structure (Number of levels and complexity of each)	X	X					
Fault Location							
Type (automatic software, automatic hardware, or manual)	X	X	X	X	X	X	
Capability (resolution and comprehensiveness)	X	X	X	X		X	
Maintainability Factor							
AGE	X	X	X	X	X	X	X*
Maintenance Concept	X	X	X	X	X	X	X*

*Varies with the maintenance location.

NOTE: Address quality and quantity of each logistics resource as a function of each maintenance location for each root.

SUB-NOTE 3 (1) Relationship of System Characteristics to Maintainability Roots (First Order)

A change in the requirement for this (quantity) ↓ / Forces a change in this → (optimum value or required value)	Parts Complexity	Functional Complexity	Type (Digital or Analog)	Accuracy	Reliability	Adjustments	Calibration	Accessibility	Standardization	Interchangeability	Packaging Structure	Fault Location Type	Fault Location Capability
A. System characteristic Complexity	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Parts					X			X					
2. Functional	X					X	X		X	X	X	X	X
3. Type (Digital or Analog)	X					X	X		X	X	X	X	X
4. Accuracy (tolerances)	X		X		X	X	X		X	X		X	X
5. Reliability								X	X	X	X	X	X
B. Maintainability Roots													
6. Adjustments	X		X	X				X	X	X			
7. Calibration (PM)	X		X	X					X				
8. Accessibility				X									
9. Standardization	X		X		X	X	X			X	X	X	X
10. Interchangeability Packaging						X			X				
11. Structure (number of levels and complexity of each)		X			X				X	X		X	X
Fault Location													
12. Type (auto-software, auto-hardware or manual)		X	X								X		
13. Resolution (for X percent confidence, comprehensiveness)		X	X								X		
C. Deployment Concept													
14. Number of Systems per Site					X	X	X	X	X	X	X	X	X
15. Number of Sites					X	X	X	X	X	X	X	X	X

Besides these relationships, it is necessary to have reliability data as a constant input to maintainability trade-offs. Although, from a maintainability standpoint, reliability is treated as a constant, maintainability should input a top level system trade wherein reliability is optimized in terms of the types of components (commercial, military standard, or high reliability) and types of testing (burn-in, etc.) conducted on those components.

SECTION 7C

MAINTAINABILITY TRADE-OFF PROCEDURES

This section contains procedures for conducting maintainability trade-offs and discusses quantitative and qualitative repair/discard trade-off procedures.

SECTION 7C MAINTAINABILITY TRADE-OFF PROCEDURES

DESIGN NOTE 7C1 - GENERAL TRADE-OFF PROCEDURES

1. GENERAL

1.1 Establish Integration and Control

1.1.1 Contractor Internal Integration and Control

1.1.2 Contractor/Procuring Agency Integration and Control

1.2 Gather Constraints and Identify System Requirements

1.3 Select Candidates

1.4 Compile Data (Quantitative and Qualitative)

1.5 Document and Tabulate

1.5 (1) Trade-Off Summary

1.6 Analyze Results

1.7 Produce Report and Obtain Approval

1.7 (1) Trade-Off Procedure Summary

2. CONTRACTOR/PROCURING AGENCY TRADE-OFF INTERFACE

DESIGN NOTE 7C2 - REPAIR/DISCARD TRADE-OFF PROCEDURE

1. GENERAL

2. QUANTITATIVE STUDIES

2 (1) Candidate Selection Flow Diagram

2 (2) Symbols

2 (3) Relationships

2.1 Study No. 1 - BITE, Hardware vs Software

2.2 Study No. 2 - BITE vs External Test Set

2.2 (1) Hardware BITE vs Software External

2.3 Study No. 3 - BITE vs Manual Fault Location

2.3 (1) Software BITE vs Manual Fault Location

2.4 Study No. 4 - External (Automatic) vs Manual Fault Location

2.4 (1) External vs Manual Fault Location

2.5 Study No. 5 - External Fault Location vs Discard at Failure

2.5 (1) External (Automatic) Fault Location vs DAF

2.6 Study No. 6 - Field vs Depot Repair

2.6 (1) Field vs Depot Repair

2.7 Study No. 7 - Discard at Failure vs Manual Fault Location

DESIGN NOTE 7C1 GENERAL TRADE-OFF PROCEDURES

1. GENERAL

The major steps of a trade study are to:

- Establish integration and control.
- Gather constraints and identify system requirements.
- Select candidates.
- Compile data (quantitative and qualitative).
- Document and calculate.
- Analyze results.
- Produce report and obtain approval.

1.1 Establish Integration and Control

1.1.1 Contractor Internal Integration and Control

This step establishes the overall approach to the trade-off, responsibility, and scheduling to ensure effective and timely results. Since the data required is generated or developed from various sources (finance, engineering, procurement, reliability, maintainability, etc.), it is essential to establish an authoritative source (task leader) for coordination of the effort.

The major tasks are to:

- Identify participants and responsibility.
- Establish data sources and requirements.
- Establish dimensions for data.
- Schedule inputs and outputs.

The definition of purpose, approach, and data requirements is an essential building block in the conduct of a trade-off. Early definition ensures that data inputs are usable as submitted, correct, and in consonance with other data inputs. A common basis must be established that will allow rapid comparison of systems advantages and disadvantages. The data base most easily understood by procuring agencies and industry is the dollar. The dollar data base establishes a cost effectiveness comparison.

1.1.2 CONTRACTOR/PROCURING AGENCY Integration and Control

The contractor/procuring agency has an interface in conducting trade-offs in which the procuring agency:

- Identifies the requirement for trade-off by specifying system acquisition based on life cycle cost.
- Identifies specific trade-off considerations in the Request for Proposal (RFP).
- Approves of manpower effort for trade-off studies submitted and identified by the contractor (in addition to those specified in the RFP, the contractor may identify requirements for other studies).
- Monitors status of trade-offs and the results, and gives concurrence or recommendations for approval.
- Is an integral factor in the overall decisions made as a result of trade-offs.

1.2 Gather Constraints and Identify System Requirements

The constraints imposed on the system due to contractual documentation, project or procuring agency decisions, system requirements, etc., should be identified at this time. The constraints imposed on a system may, in fact, eliminate the consideration of some tentative candidates due to noncompliance. The elimination of candidates based on noncompliance avoids extensive and often meaningless trade-off study effort. The constraints are identified from various sources such as:

- Contractual documentation
- Higher level analysis
- Project or procuring agency decisions

The constraints may be identified in terms of deployment, utilization, equipment, quantities, acquisition or support cost, maintenance concept, maintenance resources, maintenance time and availability, etc., each of which may affect the feasibility of design or support candidates.

The requirement for trade-offs is limited by the depth and definitiveness of the system specification. For example, if the specification states that an electromechanical system has fault isolation by built-in test equipment to a discard-at-failure maintenance (DAFM) plug-in package, a DAFM cost not more than $50, an $\overline{M}_{ct}$ of 15 minutes, and an MTBF of 700 hours, the following trade-offs are eliminated:

- Hydraulic versus electromechanical
- Repair versus throwaway
- Optimum level of repair
- External versus built-in test equipment
- Compromise between $\overline{M}_{ct}$ and MTBF to achieve a stated availability

However, to specify these requirements in the Request for Proposal or specifications, the procuring agency must have performed trade-offs to arrive at these decisions during the conceptual phase.

The contractor should be allowed flexibility in design to meet an overall requirement. Variance in requirements, if justified by trade-off, should be evaluated by the procuring agency.

1.3 Select Candidates

Based upon prior identification of the system constraints, the feasible candidates for either a design philosophy trade-off, maintainability trade-off, or maintenance support trade-off, may be identified. An adequate description of each candidate is required to ensure that all participants in the trade-off study can develop their input data adequately and on a common

understanding of candidate configuration. The baseline maintenance concept, reliability data, hardware cost, utilization concepts, and manufacturing and production techniques are types of information required for general dissemination. For example, the reliability analyst requires a system description from the systems or design engineer to perform failure rate predictions, the maintainability analyst requires the failure rates to perform apportionments and predictions, the maintenance analyst requires the failures rates to determine spares requirements, etc. Each candidate must be analyzed to assure that it meets or exceeds the operational requirements and system constraints.

1.4 Compile Data (Quantitative and Qualitative)

The participants identified in Paragraph 1.1 who are responsible for supplying data inputs into the trade-off shall compile quantitative and qualitative data as required to satisfy the data base requirements. The compilation of data is not an independent function. There is an interflow of data between participants, and this effort must be scheduled (Para 1.1) to ensure the availability of all data from all participants at the scheduled time.

1.5 Document and Tabulate

The data developed and submitted by the participants in the trade-off should be documented and tabulated in a clear, concise, and orderly manner. The cost categories previously identified collectively include all costs that would affect a cost trade-off decision. These categories are combined under the major classification of acquisition, installation, operational and maintenance, or support costs. Availability of cost data on the baseline system may be restricted or nonexistent. In this case, the candidates may be assigned best estimate cost deltas in relationship to each other.

1.6 Analyze Result

The results of the trade-off should be analyzed to determine the cost versus system effectiveness relationship or availability per dollar cost expenditure. Total cost utilized alone, unless all other factors are equal, should not be the firm basis for system selection. The increase in reliability, decrease in maintenance time, future growth potential, and performance are areas in which large improvement may be recognized in relation to slight increase in total cost. In addition, the analysis should:

- Perform parametric (or sensitivity) analysis.
- Identify additional depth requirements.
- Evaluate compliance with requirements.

Variance in data may impact the results of the study. A parametric analysis should be conducted which varies such factors as equipment quantities, range of MTBF, etc., to facilitate the rapid comparison of effects of changes on total system cost or concepts. The variance and parameter selected should be based on foreseeable realistic equipment demands or trends.

The requirement for additional depth in the trade-off or additional data requirements may be identified due to the candidates, factors being too closely related to render a decision. In these cases, the data and information should be reexamined to determine if a more comprehensive analysis of these candidates can be conducted.

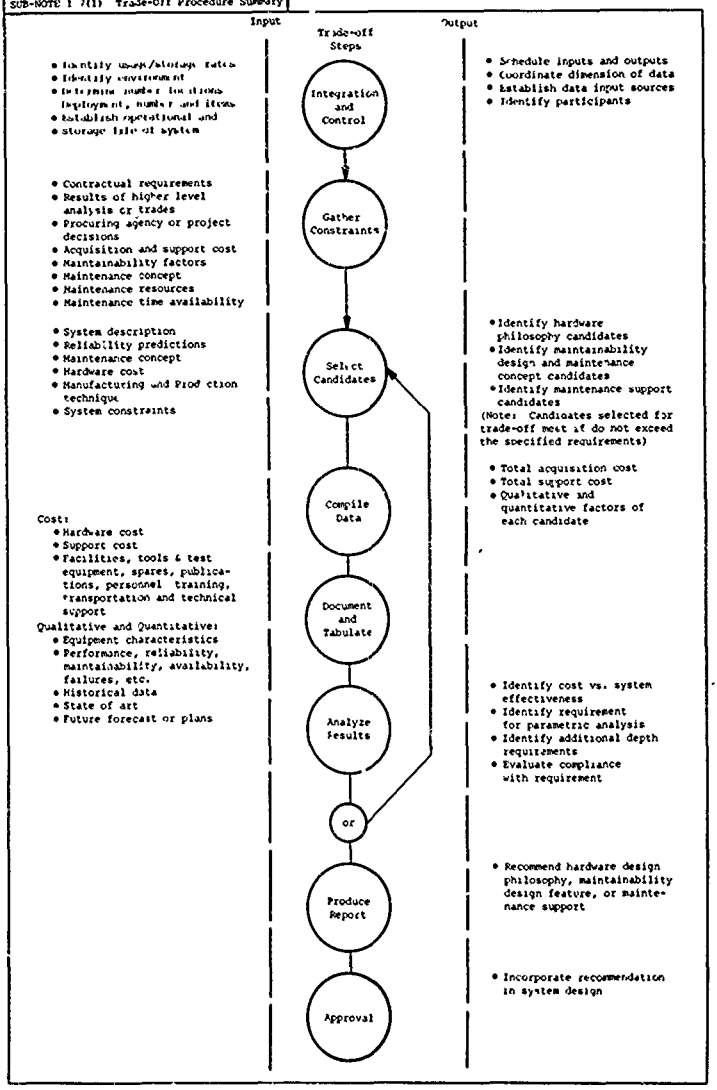
The candidates should be evaluated in relationship to their degree of compliance with the requirements. In this respect, the analyst should consider the cost/system effectiveness relationship in respect to strict compliance with or exceeding the stated requirements. Risks should be considered and identified.

1.7 Produce Report and Obtain Approval

The report presented by the contractor to the procuring agency for approval should be presented in a standard format. The format should present a summary of the report and, in addition, provide the detailed background or backup data utilized in the preparation for further analysis, if required.

Concurrence by the procuring agency on the results of recommendations of the trade-off will result in the incorporation of or implementation of the hardware design philosophy, maintainability design feature, or maintenance support concept for the system. SN 1.7 (1) presents a summary of the trade-off procedures directing the overall steps and basic input requirements and output from each step of the trade-off. The trade-off procedure is an iterative process, and trade-offs are updated as additional data becomes available; however, trade-offs should be considered final when they have resulted in final decisions and implementation of design or support concepts to such an extent that cost or schedule would be detrimentally affected by reversal of decisions.

SUB-NOTE 1 7(1) Trade-Off Procedure Summary



DESIGN NOTE 7C2 REPAIR/DISCARD TRADE-OFF PROCEDURE

1. GENERAL

The repair/discard trade-off, which is prime to maintainability, should be conducted for each system being developed.

This trade-off, which can be accomplished through the aid of a model, as described in Chapter 9, results in the following decisions:

- The number and complexity of each hardware level
- The DAF level
- The type of diagnostics for each hardware level
- The maintenance and spares concept for each hardware level

In the conduct of this trade-off, using the modeling technique described in Chapter 9, the basic problem is to narrow down the number of candidates which must be run through the model. As discussed in Chapter 9, this can be achieved, in part, by elimination of some candidates as determined from the following sources:

- Related customer or other constraints
- Operational concept

2. QUANTITATIVE STUDIES

In addition to the above methods of elimination of candidates to run through the model, the procedures below are provided. These procedures provide decisions, starting with the LRU level, for the following:

- Automatic external versus BITE versus manual diagnostics
- Field versus Depot repair
- Repair versus discard of lowest level package

These procedures include examples of computations, using assumed values which are considered representative for the Multiplexer Set but which may not fit a particular system or situation. Whenever the value used does not fit a particular application, the appropriate value should be used and the associated value or curve related to the decision should be recomputed. The methodology used for each case is the equal cost method; i.e., wherein the solution or curve (when the solution is plotted) represents that condition when the cost for each candidate is equal.

These procedures include only the first order (prime) relationships, so that when the system value is close to the decision value, the model should be used on both candidates for a final decision.

In all the illustrative studies which follow, these general assumptions are made:

- All hardware is packaged functionally (as defined in Chapter 2).
- The system is a complex system.
- The manpower required for repair considers only active repair time.
- Failure rate is in the dimension of failures/calendar hour. This can be derived by combining the nonoperating and operating rates with their appropriate time contributions.

The problem of how to get from the system to the LRU is not addressed herein, for the general case, for two reasons. The first is that the mission and/or operational requirements for a particular system will usually constrain the type of the diagnostics to get from the system to the LRU to a very few candidates, and secondly, the normal malfunction detection requirements inherently provide diagnostics at this level such that the additional diagnostics requirements are very minimal.

It should be recognized that even though the decision for automatic or manual diagnostics considers, as one of the factors, the average difference in the man-hours to perform each, there are some cases when a unit to be diagnosed is so complex that it is beyond human capability, regardless of time. If this were the case, then manual diagnostics is not an acceptable candidate.

In the studies that follow, which involve diagnostic equipment, the values used are for newly designed, system-peculiar equipment. Any trades on multi-use or general-purpose test equipment should be conducted, using the principles described herein, but assigning appropriate values considering the multi-use capability. Also, some of the nonrecurring cost factors will be dropped in this type of trade.

The candidate selection flow diagram shown in SN 2 (1) provides the sequence for conducting seven separate studies. In addition, the matrix related to each block of the diagram shows the conditions, applicability, or decisions for that block. The number accompanying some blocks is the number of the study appearing subsequent in this section. The dots directly above each block indicate all the conditions to be considered in making the decision indicated.

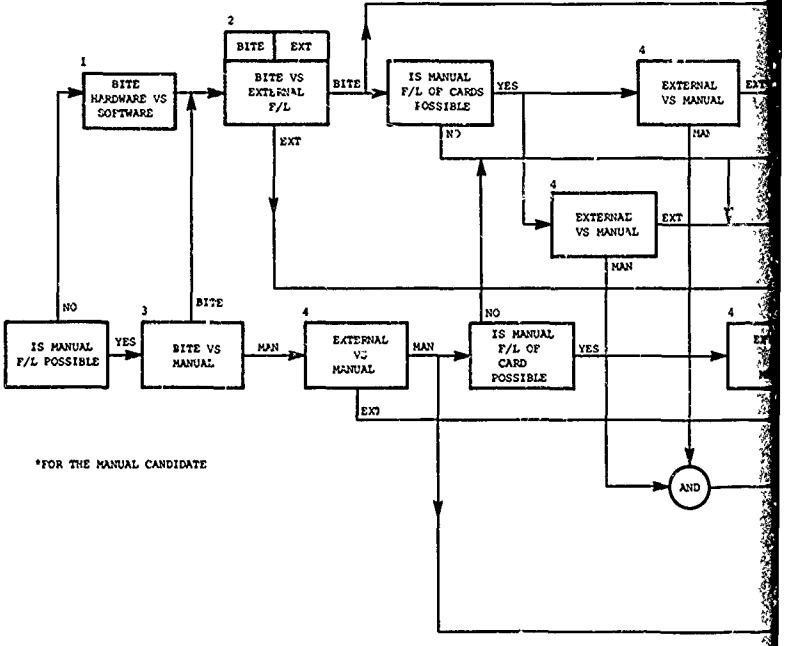
The dots on the right side of the diagram indicate the final design and maintenance concept decisions in accordance with the block(s) below them in which termination results.

It should be stated again that some candidates (or paths through this diagram) may be precluded and/or dictated due to constraints imposed on the system or because it is a technically unfeasible candidate.

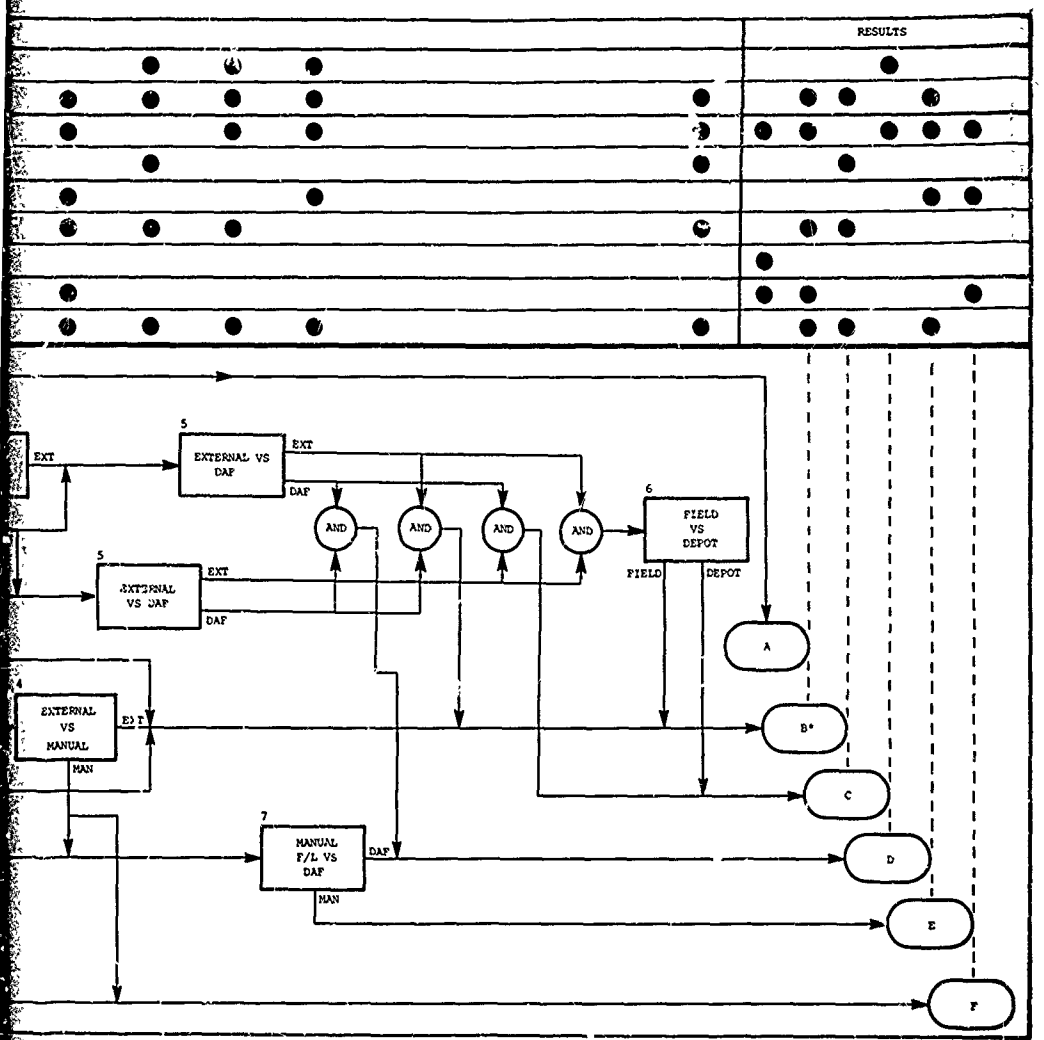
SN 2 (2) is a list of symbols used in the seven studies. Included in the list, as applicable, is the dimension of the parameter. SN 2 (3) shows the general relationships used in some of the studies.

SUB-NOTE 2 (1) Candidate Selection Flow Diagram

BLOCK PARAMETERS		
CARD POLICY	DAF — OR — REPAIR	
MAINTENANCE LOCATION	FIELD — OR — DEPOT	
FAULT LOCATION TYPE	MANUAL — OR — AUTOMATIC (EXTERNAL — OR — BITE)	
LEVEL OF FAULT LOCATION	LRU TO CARD — AND — CARD TO PIECE PART	



A



*A TERMINATION IN THIS BLOCK CANCELS A DECISION IN BLOCK A AND/OR BLOCK F (AS APPLICABLE).

SUB-NOTE 2 (2) (Sheet 1 of 2 sheets) Symbols

C_{ca} = Cost of card ($) (Production).

C_m = Manpower cost ($).

C_{sy} = System cost* ($) = $\sum C_{ca}$ (Production).

C_r = Manpower rate ($/hr).

E = Number of deployed systems.

F = Failures in an interval τ_t.

K_1 = The ratio of the nonrecurring external test set or BITE cost to the system cost. This includes both development and support required for the test set.

K_2 = The ratio of the production cost of one external test set to the system cost.

K_3 = $\frac{C_{sy}}{\lambda_{sy}}$ = Ratio of system cost to system failures/hour.

K_4 = The ratio of total number of cards in one system to the number of card types in the system. This, then, is the average utilization rate of a card type in the system.

K_5 = The ratio of cost of the BITE hardware to system cost.

K_6 = The ratio of the cost of analytical software to the system cost.

L = Program life cycle (calendar hours).

M_{ca} = Number of card types in system.

N = Constant related to probability of having a spare when required.

*System cost, as used in the following studies, is the production cost of one unit of whatever level of hardware is being diagnosed for that particular trade-off.

SUB-NOTE 2 (2) (Sheet 2 of 2 sheets) Symbols

Q = Quantity of spares required.

T_{MH} = Diagnostic time difference in man-hours/repair between manual and BITE

T_t = Turn around time from field to depot.

V = Number of sites.

λ_{ca} = Card failure rate (failures/hr).

λ_{sy}^{*} = System failure rate (failures/hr) = $\Sigma \lambda_{ca}$.

*The dimensions of λ_{sy} must be in failures per calendar hour, and for the example multiplexer system which operates full time, this is equal to the operating failure rate.

In general, however:

$$\lambda_{sy} = \frac{\lambda_o, t_o + \lambda_{no}, t_{no}}{t_o + t_{no}}$$

where λ_o is the operating failure rate

λ_{no} is the nonoperating failure rate

t_o is the operating time in a unit time $t_o + t_{no}$ (hours)

and

t_{no} is the nonoperating time in a unit time $t_o + t_{no}$

SUP-NOTE 2 (3) Relationships

$K_3 = \frac{C_{sy}}{\lambda_{sy}}$

$Q = F + N\sqrt{F}$ (This assumes that the variance is equal to the mean of the failure distributions).

N	% Probability of Having a Spare When Required
0.67	75
1.04	85
1.65	95
2.33	99

$M_{ca} = \frac{C_{sy}}{C_{ca} \cdot K_4}$

2.1 Study No. 1 - BITE, Hardware vs Software

In this study, the trade-off is between the higher cost of additional BITE required at the lower levels for hardware diagnostics, against the additional, but nonrecurring cost of analytical software development required for signature correlation of go/no-go signals at a higher level. (For definitions of hardware and software diagnostics, refer to DN 7E3.) The approach used will be to determine that system deployment quantity wherein the cost of hardware for hardware diagnostics equals the cost of hardware and software for software diagnostics.

It is assumed that the data processing hardware required for signature correlation already exists as part of the tactical system and, for this reason, all such costs are omitted from this study. Should the system being considered, however, require development and production of data processing hardware in order to effect a software approach, the associated costs must be added for purposes of the trade-off.

Hardware BITE cost:

$$K_{5(1)} \cdot C_{sy} \cdot E$$

Software BITE cost:

$$K_{5(2)} \cdot C_{sy} \cdot E + K_6 \, C_{sy}$$

∴equal costs when:

$$K_{5(1)} \cdot C_{sy} \cdot E = K_{5(2)} \cdot C_{sy} \cdot E + K_6 \cdot C_{sy}$$

$$E = \frac{K_6}{\left[K_{5(1)} - K_{5(2)}\right]} \qquad (1)$$

Assume

$K_{5(1)} = 0.3$

$K_{5(2)} = .05$

IC complexity = 5,000

$$C_{sy} = 50,000$$

$$K_6 = \frac{4,000 \text{ MH} \times 25}{50,000} = 2 \qquad \text{(Ref. DN 7E2, SN 3.4 (3))}$$

Substituting values

$$E = \frac{2}{(0.3 - 0.05)}$$

$$E = 8$$

which says that for deployment quantities up to 8, hardware BITE is the choice, and for quantities beyond 8, an analytical software BITE approach is more cost effective.

SN 3.4 (1) in DN 7E2 shows the relationship between the complexity of the item under test and the ratio of BITE to the item complexity. Restated, it says that as an item or system becomes more complex, the percentage of hardware required to test it becomes less. This holds true for varying complexities within a functional entity. It does not hold true, however, when complexity is increased by introduction of additional functional entities within the same framework. For example, the inclusion of a receiver, with 5 percent BITE, within a transmitter assembly which contains the same degree of BITE, yields a more complex system, but with the same overall 5 percent BITE. This is so because the new assembly is now composed of two functional entities, each of which must be individually tested.

2.2 Study No. 2 - BITE vs External Test Set

In this study, the trade-off is between the cost of one test set per site against a test capability in every system (BITE).

Software BITE:

$$K_5 \cdot C_{sy} \cdot E + K_6 \cdot C_{sy}$$

Software External:

$$K_2 \cdot C_{sy} \cdot V + K_6 \cdot C_{sy}$$

∴ equal cost when:

$$K_5 \cdot C_{sy} \cdot E + K_6 \cdot C_{sy} = K_2 \cdot C_{sy} \cdot V + K_6 \cdot C_{sy}$$

$$\boxed{\frac{E}{V} = \frac{K_2}{K_5}} \qquad (2)$$

Assume $K_2 = 0.47$

$K_5 = 0.05$

Substituting values:

$$\frac{E}{V} = \frac{0.47}{0.05} = 9.4$$

which says that for 10 or more systems per site, an external software test set is the choice.

If the trade-off is between hardware BITE and software external, the following relationships hold true:

Hardware BITE:

$$K_5 \cdot C_{sy} \cdot E$$

Software External:

$$K_2 \cdot C_{sy} \cdot V + K_6 \cdot C_{sy}$$

∴ equal cost when

$$K_5 \cdot C_{sy} \cdot E = K_2 \cdot C_{sy} \cdot V + K_6 \cdot C_{sy}$$

$$\boxed{\frac{E}{V} = \frac{1}{V}\,\frac{K_6}{K_5} + \frac{K_2}{K_5}} \qquad (3)$$

Assume $K_6 = 2$

$K_2 = 0.47$

$K_5 = 0.3$

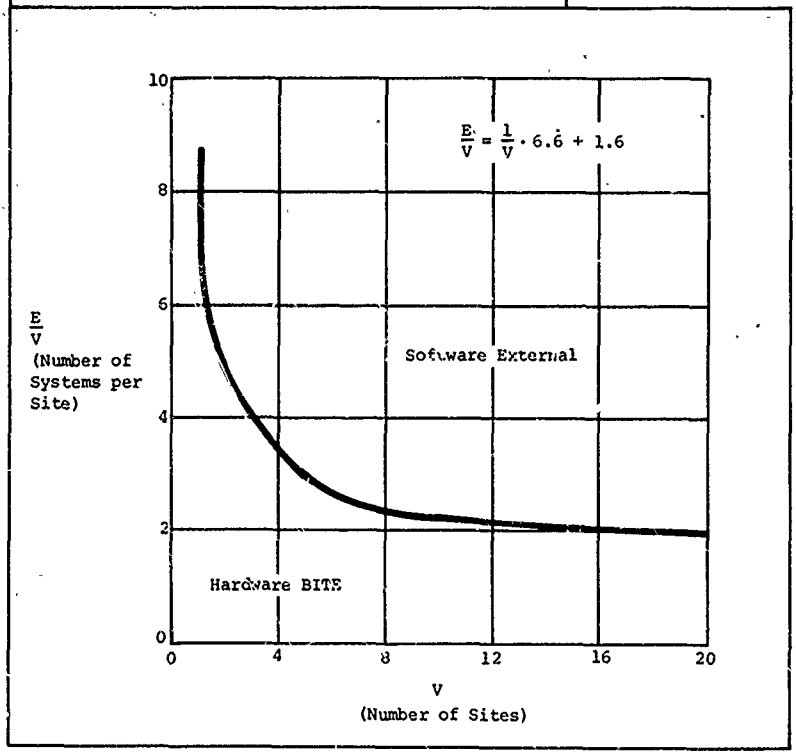
Substituting values

$$\frac{E}{V} = \frac{1}{V}\left(\frac{2}{0.3}\right) + \frac{0.47}{0.3}$$

$$\frac{E}{V} = \frac{1}{V} \cdot 6.6 + 1.6$$

See SN 2.2 (1) for a plot of the equal cost curve.

(SUB-NOTE 2.2 (1) Hardware BITE vs Software External



2.3 Study No. 3 - BITE vs Manual Fault Location

In this study, the trade-off is between the cost of BITE in each system (E) against the increased labor to perform manual fault location for the life of the program.

Hardware BITE cost:

$$K_5 \cdot C_{sy} \cdot E$$

Manual cost:

$$L \quad \lambda_{sy} \quad C_r \quad T_{MH} \quad E$$

∴ Equal costs when:

$$K_5 \cdot C_{sy} \cdot E = L \cdot \lambda_{sy} \cdot C_r \cdot T_{MH} \cdot E$$

but $K_3 = \dfrac{C_{sy}}{\lambda_{sy}}$

so: $$\boxed{K_5 = \frac{L \cdot C_r \cdot T_{MH}}{K_3}} \qquad (4)$$

Assume (for Multiplexer Set)

$L = 87{,}660$

$C_r = 10$

$T_{MH} = 5$

$K_3 = 1.67 \times 10^8$

Substituting values:

$$K_{5(H)} = \frac{87{,}660 \cdot 10 \cdot 5}{1.67 \times 10^{8}}$$

$$K_{5(H)} = 0.026$$

This shows that even when ignoring the K_1 term, hardware BITE is only a viable candidate if its cost does not exceed 2.6 percent of the production cost of a system. Since hardware BITE is typically 30 percent or more of system cost for diagnostics to the card level (through utilization of malfunction detection capability, at the card level), there will be few occasions when it will be in contention with the manual approach. Furthermore, there are no disciplines, other than maintainability, which would require malfunction detection at the card level as BITE, further precluding hardware BITE as a candidate.

Given that the mission requirement creates the need for a significant degree of malfunction detection, however, software diagnostics must be considered if the additional BITE hardware required for maintainability to attain the specified resolution is less than 2.6 percent. The nonrecurring cost of analytical software development is prorated over the number of systems deployed, and it is the systems deployed versus the cost of additional BITE hardware which determines the characteristics of an equal cost curve.

Software BITE cost:

$$K_5 \cdot C_{sy} \cdot E + K_6 \cdot C_{sy}$$ (the K_1 term is charged against the malfunction detection requirement and is therefore omitted)

Manual cost:

$$L \cdot \lambda_{sy} \cdot C_r \cdot T_{MH} \cdot E$$

$\therefore$ equal costs when:

$$K_5 \cdot C_{sy} \cdot E + K_6 C_{sy} = L \cdot \lambda_{sy} \cdot C_r \cdot T_{MH} \cdot E$$

but $K_3 = \dfrac{C_{sy}}{\lambda_{sy}}$

so:
$$E = \frac{K_6}{\frac{L \cdot C_r \cdot T_{MH}}{K_3} - K_5} \qquad (5)$$

Assume (for Multiplexer Set)

$L = 87{,}660$

$C_r = 10$

$T_{MH} = 5$

$K_3 = 1.67 \times 10^8$

$K_6 = 2$

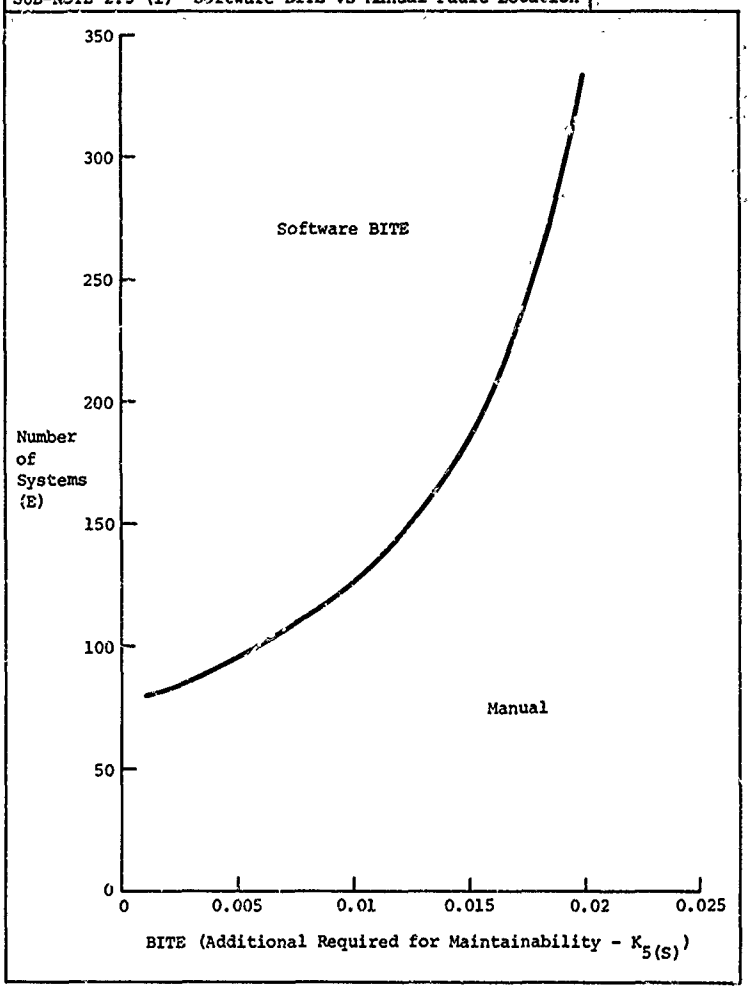
For $K_5 = 0.001$

$$E = \frac{2}{\frac{87{,}660 \cdot 10 \cdot 5}{1.67 \times 10^8} - 0.001}$$

$E = 80$

The equal cost curve depicted by SN 2.3 (1) was obtained by substituting increments of K_5 from 0.02 to 0.001.

SUB-NOTE 2.3 (1) Software BITE vs Manual Fault Location



2.4 Study No. 4 - External Software vs Manual Fault Isolation

In this study, as in the BITE versus manual study, the cost of the test equipment is being compared to manpower saved by use of that test set. It is assumed that the same test set could be used to test from the LRU to card level and from the card to piece part level.

The values assumed for T_{MH} consider the following factors regarding manual isolation.

- Some trial and error is involved, resulting in multiple substitution and subsequent retesting.
- At least two men are involved in this type maintenance.

Cost of test sets:

$$K_1 \cdot C_{sy} + K_6 \cdot C_{sy} + K_2 \cdot C_{sy} \cdot V$$

Cost of maintenance manpower:

$$C_r \cdot \lambda_{sy} \cdot E \cdot T_{MH} \cdot L$$

∴ equal costs occur when:

$$K_1 \cdot C_{sy} + K_6 \cdot C_{sy} + V \cdot K_2 \cdot C_{sy} = C_r \cdot \frac{C_{sy}}{K_3} \cdot E \cdot T_{MH} \cdot L$$

$$\text{or } \frac{E}{V} = \frac{1}{V}\left[\frac{K_3 (K_1 + K_6)}{C_r \cdot T_{MH} \cdot L}\right] + \frac{K_2 \cdot K_3}{C_r \cdot T_{MH} \cdot L} \qquad (6)$$

Assume

$C_r = 10$

$K_1 = 7.1$ (4.4 development + 2.7 support)

$K_2 = 0.47$

$K_3 = 1.67 \times 10^8 = \left(\frac{35{,}000}{210 \times 10^{-6}}\right)$

$K_6 = 2$

$T_{MH} = 5$ (LRU to card), 10 (card to piece part), and 15 (LRU to piece part).

$L = 87{,}660$ (10 years)

Substituting the reference values (for fault location from LRU to piece part, $T_{MH} = 15$)

$$\frac{E}{V} = \frac{1}{V}\left[\frac{1.67 \times 10^8 (7.1 + 2)}{10 \cdot 15 \cdot 87{,}660}\right] + \frac{0.47 \cdot 1.67 \times 10^8}{10 \cdot 15 \cdot 87{,}660}$$

$$\frac{E}{V} \doteq \frac{1}{V} \cdot 116 + 6$$

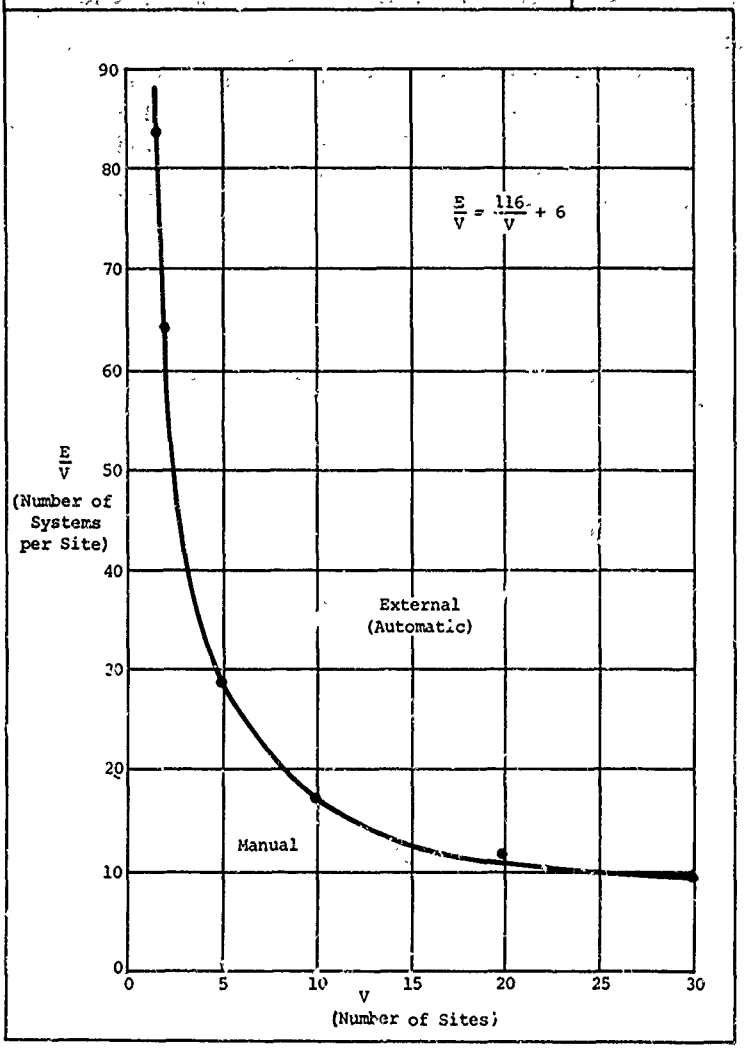
See SN 2.4 (1) for a plot of the equal cost curve.

A similar curve, if required, can be derived for LRU to card level ($T_{MH} = 5$) or card level to piece part ($T_{MH} = 10$) by using equation (6).

Discussion:

When using this study for the card to piece part case, it should be run twice; once as indicated and once when setting V = 1 (this assumes depot maintenance even if there is actually more than one site).

SUB-NOTE 2.4(1) External vs Manual Fault Location



2.5 Study No. 5 - External Fault Location (Repair) vs Discard at Failure

By analysis of the detailed trade study conducted on the Multiplexer Set (See Sect 7D), it can be seen that in the range where the decision is made regarding DAF versus RAF of cards, the factors which are first order (prime) in making this decision are the cost of the test set for the RAF candidate compared to the cost of spare cards for the DAF candidate.

Cost of spare cards:

$$\lambda_{sy} \cdot L \cdot C_{ca} \cdot E$$

Cost of test sets:

$$K_1 \cdot C_{sy} + K_6 \cdot C_{sy} + K_2 \cdot C_{sy} \cdot V$$

$\therefore$ equal cost occurs when:

$$\lambda_{sy} \cdot L \cdot C_{ca} \cdot E = K_1 \cdot C_{sy} + K_6 \cdot C_{sy} + K_2 \cdot C_{sy} \cdot V$$

or:

$$\frac{L \cdot C_{ca} \cdot E}{K_3} = K_1 + K_6 + K_2 \cdot V$$

$$\boxed{C_{ca} \cdot E = K_3\left(\frac{K_1 + K_6 + K_2 \cdot V}{L}\right)} \qquad (7)$$

Assume

$$L = 87{,}660$$
$$K_3 = 1.67 \times 10^8$$
$$K_1 = 7.1$$
$$K_2 = 0.47$$
$$K_6 = 2$$

Substituting reference values:

for V = 1:

$$C_{ca} \cdot E = \frac{1.67 \times 10^8 \quad (7.1 + 2 + 0.47 \cdot 1)}{87{,}660}$$

$$C_{ca} \cdot E = 13{,}200$$

for V = 10

$$C_{ca} \cdot E = \frac{1.67 \times 10^8 \quad (7.1 + 2 + 0.47 \cdot 10)}{87{,}660}$$

$$C_{ca} \cdot E = 26{,}300$$

This equation is depicted graphically in SN 2.5 (1).

Discussion

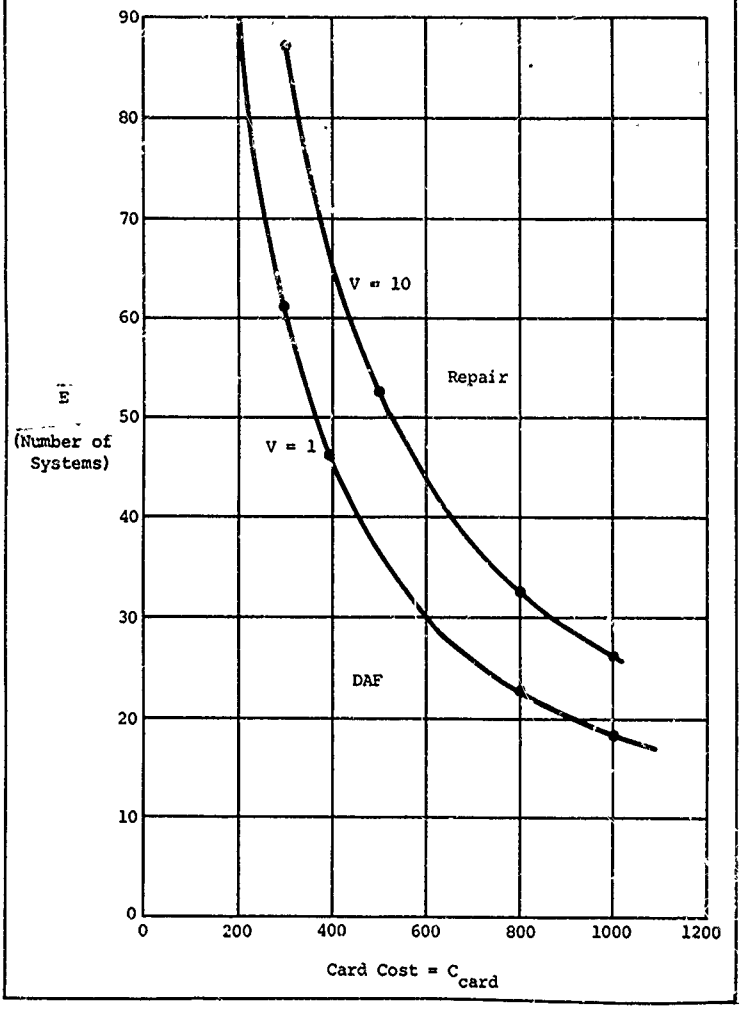
It can be seen that for a card cost of $475, and for the values assumed, the breakeven quantity of deployed systems (E) is 39 for one-site deployment.

The depot test versus DAF candidate can be solved by simply setting V = 1, regardless of the number of actual sites.

Notice that when there are 10 sites, with cards costing $475, it takes 55 systems (E) to break even. This, though, is only 5.5 systems per site.

Equation (7) can be used to compute the $C_{ca} \cdot E$ product where the values used for K_1, K_2, K_3, or L do not fit a particular situation.

SUB-NOTE 2.5(1) External (Automatic) Fault Location vs DAF



2.6 Study No. 6 - Field vs Depot Repair

In this decision, there are two prime factors: the cost of the pipeline spares for depot repair versus the unit cost of a test set at each site.

Pipeline spares cost:

$$C_{ca} \cdot M_{ca} \cdot Q$$

where $Q = F + N\sqrt{F}$

and $F = \lambda_{ca} \cdot T_t \cdot K_4 \cdot E$

The cost of test sets:

$$K_2 \cdot C_{sy} \cdot (V-1)$$

∴ Equal costs occur when:

$$C_{ca} \cdot M_{ca} \left[\lambda_{ca} \cdot T_t \cdot K_4 \cdot E + N\sqrt{\lambda_{ca} \cdot T_t \cdot K_4 \cdot E}\right] = K_2 \cdot C_{sy} \cdot (V-1)$$

but $M_{ca} = \dfrac{C_{sy}}{C_{ca} \cdot K_4}$

so: $\lambda_{ca} \cdot T_t \cdot E + \dfrac{N}{K_4}\sqrt{\lambda_{ca} \cdot T_t \cdot K_4 \cdot E} = K_2 \cdot (V-1)$

(using the quadratic equation)

$$\lambda_{ca} \cdot E = \frac{2K_2 (V-1) + \frac{N^2}{K_4} - \frac{1}{K_4}\sqrt{4K_2 \cdot K_4 (V-1) N^2 + N^4}}{2T_t} \quad (8)$$

Assume

$K_2 = 0.47$

$N = 2$ (This results in approximately a 98 percent probability of having a spare when required)

$K_4 = 2.5$

$T_t = 1440$ (2 months)

Substituting values

$$\lambda_{ca} \cdot E = \frac{2 \cdot 0.47\ (V-1) + \frac{2^2}{2.5} - \frac{1}{2.5}\sqrt{4 \cdot 0.47 \cdot 2.5\ (V-1) \cdot 2^2 + 2^4}}{2 \cdot 1440}$$

$$\lambda_{ca} \cdot E = \frac{0.94\ (V-1) + 1.6 - 1.6\sqrt{1.175\ (V-1) + 1}}{2880}$$

for $V = 2$, $\lambda_{ca} \cdot E = 62.5 \times 10^{-6}$

for $V = 11$, $\lambda_{ca} \cdot E = 1760 \times 10^{-6}$

The equal cost curves are provided in SN 2.6 (1).

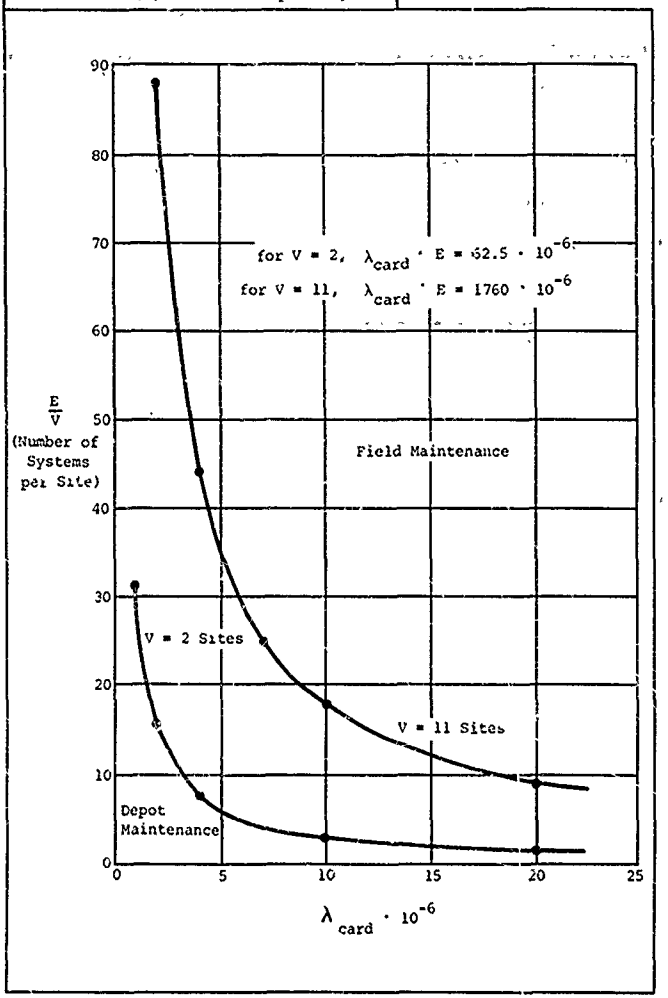
Discussion

For the example system, the average card failure rate is 2.84×10^{-6} failures per hour so that, with the 2-month pipeline assumed, the break even point would be 22 systems per site with a test set at two sites.

It can also be seen that if the deployment calls for 11 sites (V=11), then it takes 62 systems per site to break even. In any case, an increase in the systems per site is more in favor of the field repair.

Actually the technique used in this study is applicable to any level of hardware once the variables are adjusted according to the level of hardware being treated.

SUB-NOTE 2.6(1) Field vs Depot Repair



2.7 Study No. 7 - Discard at Failure vs Manual Fault Location (Repair)

Cost of DAF:

$$\lambda_{sy} \cdot L \cdot C_{ca} \cdot E$$

Cost of manual repair:

$$C_r \cdot T_{MH} \cdot E \cdot \lambda_{sy}$$

∴equal costs when:

$$\boxed{C_{ca} = C_r \cdot T_{MH}} \quad (9)$$

$$C_{ca} = 10 \cdot 10 = \$100$$

This says that cards should be repaired if their cost exceeds $100.

SECTION 7D

MULTIPLEXER SET TRADE-OFF EXAMPLE

This section contains an example of a card and module discard versus repair trade-off for the Multiplexer Set.

SECTION 7D MULTIPLEXER SET TRADE-OFF EXAMPLE

DESIGN NOTE 7D1 - DISCARD VERSUS REPAIR COST ANALYSIS FOR MULTIPLEXER SET PRINTED CIRCUIT CARDS AND MODULES

1. INTRODUCTION
2. SUMMARY AND CONCLUSIONS
3. EQUIPMENT DESCRIPTION
3(1) Typical Printed Circuit Board Layout
3(2) Typical Module Layout
3(3) Board/Module Data
3(4) 10-Year Failure Quantities
4. CANDIDATE DESCRIPTION
4.1 Discard-at-Failure (DAF) Candidate
4.2 Repair-at-Failure (RAF) Candidate
4(1) DAF Correction Process
4(2) RAF Correction Process
5. GUIDELINES AND ASSUMPTIONS
5.1 Guidelines
5.2 Assumptions
6. DAF COST FACTORS
6(1) 10-Year DAF Subassembly Cost
7. RAF COST FACTORS
7.1 Nonrecurring RAF Cost
7.1.1 Depot or SRA Repair AGE
7.1.2 Depot Repair Pipeline Cost

7.1.2(1) Depot or SRA Repair and Resupply Lines

7.1.2(2) Items Required in Repair Pipeline for Varying Multiplexer Set Equipment Quantities

7.1.2(3) Repair Pipeline Cost for Varying Multiplexer Set Equipment Quantities

7.1.3 Supply Administration Cost

7.2 Recurring RAF Costs

7.2.1 Packaging and Transportation Cost

7.2.1(1) 10-Year Packaging and Transportation Costs

7.2.2 Depot or SRA Repair Labor

7.2.2(1) Typical Item Repair Sequence

7.2.2(2) 10-Year Depot or SRA Repair Labor Costs for Varying Multiplexer Set Equipment Quantities

7.2.3 Depot or SRA Repair Part Cost

7.2.3(1) 10-Year Repair Part Cost

8.0 DAF/RAF COST COMPARISON

8(1) DAF/RAF Cost Summary - Modules

8(2) DAF/RAF Cost Summary - Digital Cards

8(3) DAF/RAF Cost Comparison

9. CONCLUSIONS AND RECOMMENDATIONS

10. REFERENCES

DESIGN NOTE 7D1 DISCARD VERSUS REPAIR COST ANALYSIS FOR MULTIPLEXER SET PRINTED CIRCUIT CARDS AND MODULES

1. INTRODUCTION

This design note describes the approach, methods, and findings of a cost-effectiveness trade study performed as part of the Multiplexer Set maintainability program. The objective of this study was to define the most cost-effective disposition mode for printed circuit cards and line interface modules comprising the Multiplexer Set.

Note that this example, which considers all factors, concludes that 43 systems deployed is the breakeven point for digital card repair at the depot versus DAF. Study 4 in section 7C concludes that the breakeven point is 39 systems. This correlation would indicate the validity of using the abbreviated technique.

2. SUMMARY AND CONCLUSIONS

This analysis compares costs associated with repair and discard maintenance concepts for failed Multiplexer Set printed circuit cards and modules. These costs are computed for varying quantities of Multiplexer Set equipments, and are predicated upon a 10-year operational service life.

The discard candidate considers only failed item replacement costs, while the repair candidate considers a number of recurring and nonrecurring costs such as AGE, AGE support, labor, and repair parts costs.

The results of this analysis indicate that a repair concept is most cost effective as the quantity of supported equipments exceeds approximately 60. When the quantity of supported equipments is increased to 100, the repair concept cost advantage becomes nearly $600,000, and at 500 equipments, is approximately $5 million.

If operational equipment quantities are to exceed approximately 60, it is recommended that a depot or SRA card and module repair concept be selected.

3. EQUIPMENT DESCRIPTION

The majority of active components comprising the Multiplexer Set are mounted upon plug-in printed circuit boards within each of two chassis , or within EMI/RFI protected modular enclosures which plug into sockets at the rear of each chassis.

The printed circuit boards are approximately 7.00 inches wide, 7.25 inches high, and 0.06 inch thick. The construction of the board is either multilayer or double sided, depending on functional complexity, and provides surface area for mounting of up to 64 dual in-line integrated circuit packages (DIP's) of the 14-pin configuration.

Some of the Multiplexer Set boards have integrated circuits of the 16-pin and 24-pin configurations. Correspondingly fewer of these devices can be mounted on a typical printed circuit board.

Interface between the board and the chassis wiring plane is achieved by an edge-loaded 90-pin connector arrangement.

The circuits contained on the boards are three functional types: transistor-transistor logic (TTL), analog, and electromechanical switching matrices. As will be noted later in this report, the test equipment required for board repair is largely dictated by the type of function performed by the board.

Modules comprising the Multiplexer Set house circuits which interface the Multiplexer Set with its various input/output lines. Module circuits perform signal conditioning functions, such as amplification and impedance matching, and are essentially analog in type.

Typically, the modules are 3.0 inches high, 3.75 inches wide, and 1.0 inch thick. The circuits within each module are discrete and thick film hybrid types.

Hybrid substrates are contained within hermetically sealed cans of the TO-8 configuration. A typical module contains three hybrid circuits, and associated discrete components, mounted upon two physically separated printed circuit boards. Electrical interface between the modules and the Multiplexer Set chassis is achieved by a multipin/socket arrangement. SN 3(1) and SN 3(2) depict typical printed circuit board and interface module arrangements.

SN 3(3) lists the printed circuit boards and modules to be considered in the discard versus repair analysis. Also indicated in SN 3(3) is the failure rate for each item, its functional type (module, digital board, analog board, or electromechanical board), and the quantity of failures the item is expected to yield for one continuously operating Multiplexer Set over the 10-year Multiplexer Set service life.

Except as noted, the failure rate data listed in SN 3(3) was obtained from reference 4 (Para 10). Item quantities are predicated upon a 20-channel Multiplexer Set production configuration, supplemented (per SN 3(3)) with coarse rate and transition converters/deconverters of quantities proportional to those being delivered under the current contract.

SN 3(4) graphically depicts the expected 10-year quantities of failed items for varying quantities of fielded Multiplexer Set equipments.

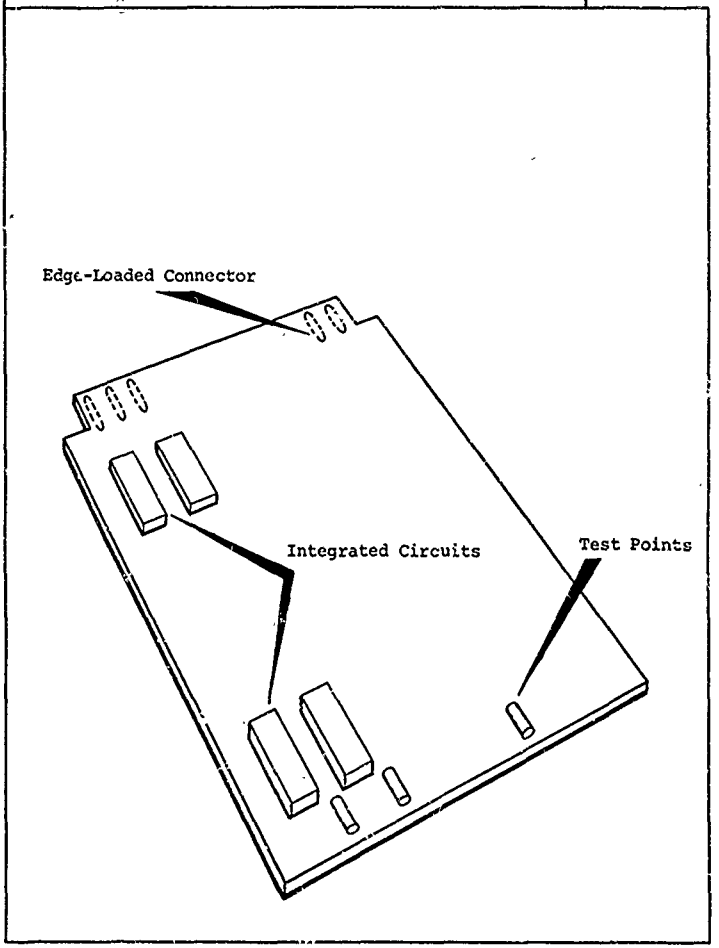
4. CANDIDATE DESCRIPTION

Two disposition modes for failed printed circuit cards and modules are considered by this study. These are discard at failure (DAF) of the malfunctioned item, and repair at failure (RAF) of the malfunctioned item at a depot or Special Repair Activity (SRA). Each candidate mode is briefly described in the following paragraphs.

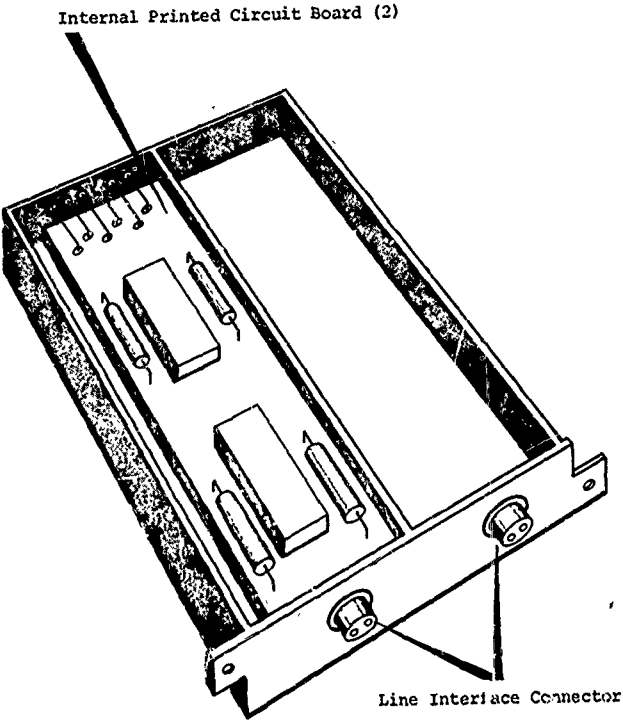
4.1 Discard-at-Failure (DAF) Candidate

For this candidate, equipment malfunctions occurring in module or printed circuit board components are corrected by replacement and discard of the

SUB-NOTE 3(1) Typical Printed Circuit Board



SUB-NOTE 3(2) Typical Module Layout (Cover Removed)



SUB-NOTE 3(3) (Sheet 1 of 2 sheets) Board/Module Data

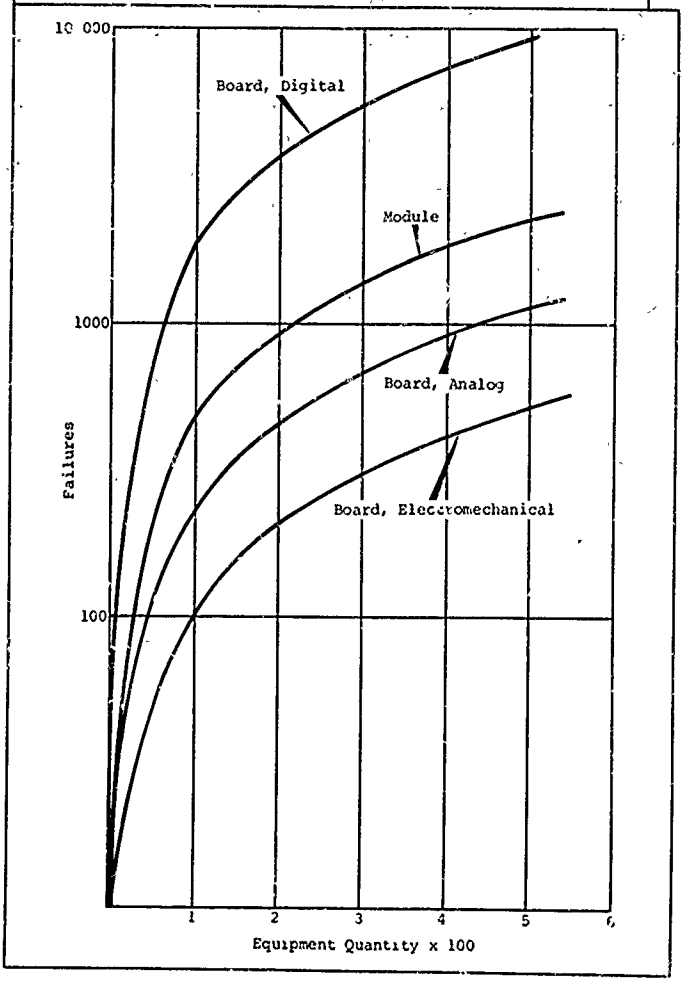
Item	Part No.	Type	Failure Rate*	No. Items Per Set	Set Failure Rate*	Failures per Set Life Cycle
Multiplexer						
Line driver module	3000	M	1.180	1	1.180	0.103
Line receiver module	4000	M	1.378	20	27.560	2.414
Rate comparison buffer	8100	D	2.162	20	43.240	3.788
Source-transmission Rate converter	28200	D	2.822	3	8.466	0.742
Transition encoder	8300	D	3.698	1	3.698	0.324
Mux reference timer	8400	A	5.454	1	5.454	0.478
Port sequencer	8510	D	3.373	1	3.373	0.296
Input/output module sequencer	8520	D	2.743	1	2.743	0.240
Gated clocks	8530	D	2.813	1	2.813	0.246
Input/output module sequencer diagnostics	8540	D	1.763	1	1.763	0.154
Overhead enable generator	8550	D	0.713	1	0.713	0.063
Overhead data generator	8560	D	3.513	1	3.513	0.308
Mux common function generator	8570	D	3.596	1	3.596	0.315
Mux channel error readout	8580	D	3.398	1	3.398	0.298
Data multiplexer	8590	D	3.373	1	3.373	0.296
Mux remote alarms	8600	A	1.540	1	1.540	0.135
Mux lamp driver card	8610	D	0.713	2	1.426	0.125
Strapping switches	8900	E	3.348	1	3.348	0.293
Power supply monitor		A	6.135	1	6.135	0.537
Demultiplexer	61830000					
Line driver module	33500	M	1.156	20	23.120	2.025
Line receiver module	34500	M	2.178	1	2.178	0.191
Smoothing buffer, low-speed	38155	D	3.726	17	63.342	5.549
Smoothing buffer, high-speed	38105	D	3.401	3	10.203	0.894
Transmission-source rate converter, high-speed	38205	D	3.921	1	3.921	0.343
Transmission-source rate converter, low-speed	38255	D	3.686	2	7.372	0.646

SUB-NOTE 3(3) (Sheet 2 of 2 sheets) Board/Module Data

Item	Part No.	Type	Failure Rate*	No. Items Per Set	Set Failure Rate*	Failures per Set Life Cycle
Transition decoder	38355	D	3.586	1	3.586	0.314
Demux lamp driver	38410	D	0.783	1	0.783	0.069
Port sequencer	28510	D	3.373	1	3.373	0.296
Variable length shift register	38515	D	2.883	2	5.766	0.505
Input/output module sequencer	28520	D	2.743	1	2.743	0.240
Minor frame sync	38525	D	3.583	1	3.583	0.314
Gated clocks	28530	D	2.813	1	2.813	0.246
Input/output mode sequencer diagnostics	28540	D	1.763	1	1.763	0.154
Channel error readout	38545	D	2.659	1	2.659	0.233
Minor frame generator bit decoder	38555	D	3.105	1	3.105	0.272
Word counter and overhead code generator	38565	D	3.233	1	3.233	0.283
Common function generator	38575	D	3.825	1	3.825	0.335
Remote alarms	38650	A	2.536	1	2.536	0.222
PLL synthesizer	38855	A	2.000**	1	2.000	0.175
Synchesizer distribution	38865	E	2.000**	1	2.000	0.175
Oscillator carrier	38875	A	2.000**	1	2.000	0.175
PLL timing generator No. 1	38825	D	4.031	1	4.031	0.353
PLL timing generator No. 2	38835	D	2.941	1	2.941	0.258
Timing distribution matrix	38845	E	3.100	1	3.100	0.272
Strapping switches	28900	E	3.348	1	3.348	0.293
Power supply monitor	---	A	6.135	1	6.135	0.537

*Failures/10^6 hours
**Best estimate

SUB-NOTE 3(4) 10-Year Failure Quantities, by Item Type, for Varying Multiplexer Set Equipment Quantities



failed item (module or board). For approximately 60 percent of all equipment failures, the automatic diagnostic feature yields a one-item callout. In those cases where this diagnostic feature yields a two- or three-item callout, all are replaced to restore equipment operation. At some later time, when the equipment is removed from service, or when an off-line equipment is available, the replaced grouping of items is sequentially substituted into the equipment until the specific malfunctioning item is identified. This item is then discarded, and remaining items in the previously replaced group are returned to the local supply activity for subsequent reissue. SN 4.1(1) graphically depicts the DAF correction sequence.

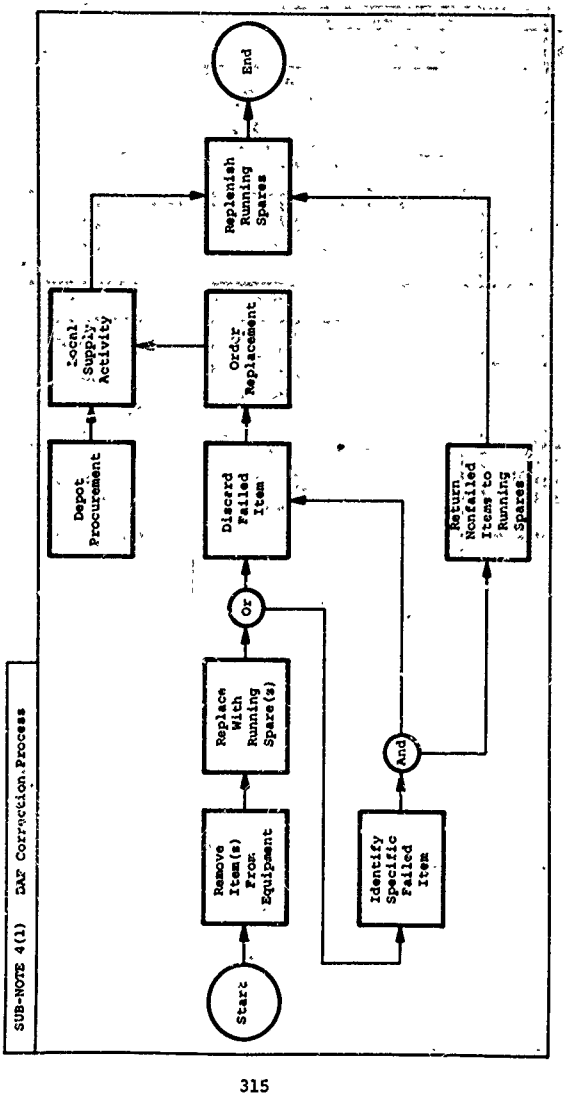
4.2 Repair-at-Failure (RAF) Candidate

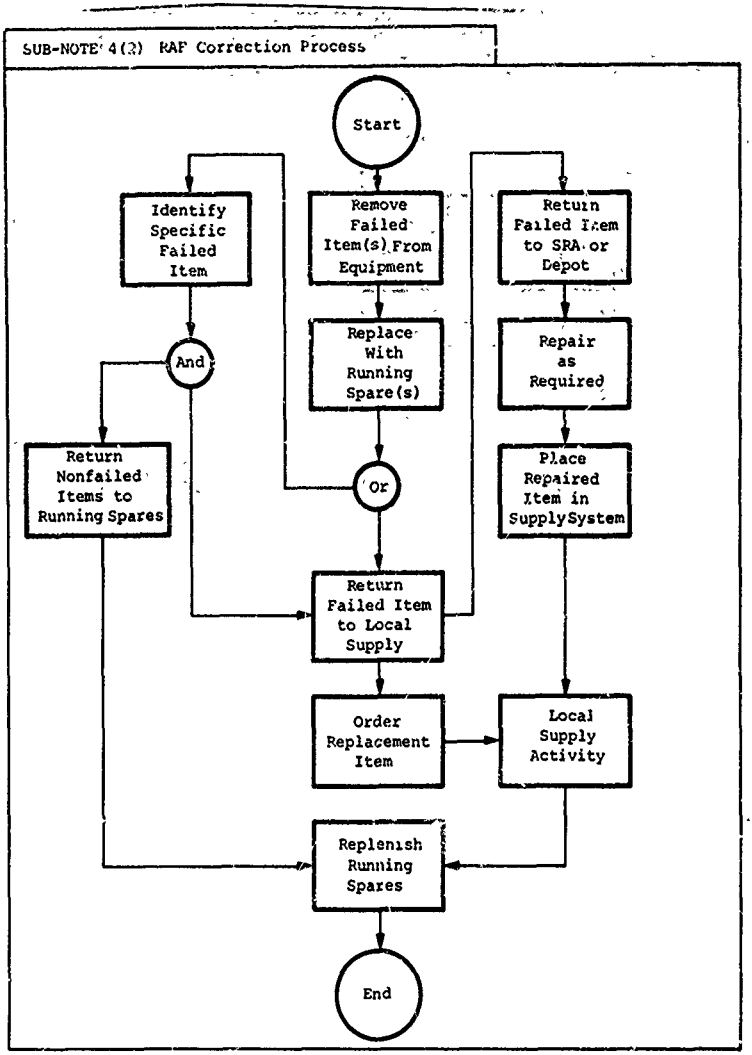
Action taken for the RAF candidate is similar to that for the DAF candidate, except that the specific failed item is not discarded. Instead, the failed printed circuit card or module is returned to the local supply activity as a "failed item" status. The supply activity prepares appropriate documentation routing the item to a depot or SRA facility, and packages the item for shipment via conventional logistical carriers. At the depot or SRA facility, the failed item is received and unpackaged, logged into the repair sequence, and inspected and repaired as necessary. Following repair and retest, the item is again placed into the supply system for subsequent reissue to using activities as a serviceable spare. SN 4.2(1) graphically depicts the RAF correction sequence.

5 GUIDELINES AND ASSUMPTIONS

A number of noncost factors associated with the deployment and use of the Multiplexer Set have a bearing upon the cost effectiveness of one candidate relative to another.

Some of these factors are adequately defined in the current contract or in contractually developed documentation. Others have been wholly or partially defined by guidance conferences and meetings held since contract award.


SUB-NOTE 4(1) DAF Correction Process
Start
Remove Item(s) From Equipment
Replace With Running Spare(s)
Or
Discard Failed Item
Depot Procurement
Local Supply Activity
Order Replacement
Replenish Running Spares
End
Identify Specific Failed Item
And
Return Nonfailed Items to Running Spares


SUB-NOTE 4(2) RAF Correction Process
Start
Identify Specific Failed Item
Remove Failed Item(s) From Equipment
Return Failed Item to SRA or Depot
And
Replace With Running Spare(s)
Repair as Required
Return Nonfailed Items to Running Spares
Or
Place Repaired Item in Supply System
Return Failed Item to Local Supply
Order Replacement Item
Local Supply Activity
Replenish Running Spares
End

There remains, however, a category of factors for which no definition is available. For purposes of this analysis, assumptions regarding these factors have been made and are identified as such in subsequent discussions.

5.1 Guidelines

The following are guidelines which are pertinent to the DAF/RAF analysis, and which have been obtained from the current contract, contractually developed documentation, or meetings and conferences held subsequent to contract award:

a. Deployment of the Multiplexer Set will be worldwide, perhaps to 100 or more separate locations.

b. Average equipment quantities will be four to five per deployment location, but may be considerably more in specific instances.

c. Skills expected to be available for the use and maintenance of recommended support equipment are of -5 and -7 levels.

d. If requirements for support equipment peculiar to the Multiplexer Set are identified, it is preferred that recommendations satisfying these requirements emphasize compatibility with lower skill levels.

e. Failure rates of the Multiplexer Set and its various components are as reflected in current reliability predictions.

f. The service life of the Multiplexer Set is 10 calendar years.

5.2 Assumptions

Listed below are assumptions made to facilitate completion of the DAF/RAF analysis. Some of these assumptions are predicated upon the guidelines identified in Paragraph 5.1, while the remainder have basis only in a "best estimation" process:

a. Operation of the Multiplexer Set is essentially continuous, with downtime being incurred only for corrective and preventive maintenance and equipment reconfiguration.

b. Deployed equipments are evenly divided between overseas (OS) and stateside (CONUS) geographical locations.

c. The quantity of deployed Multiplexer Set equipments is variable, but will not exceed 500 sets.

6. DAF COST FACTORS

The primary expense incurred with the DAF candidate is the cost of replacing failed cards and modules which have been removed from the equipment and discarded. This cost is a function of the number of such items which must be replaced, and their respective cost.

For purposes of this analysis, estimated replacement costs for the various discarded subassembly types are based upon average budgetary values reflected in the Multiplexer Set Recommended Spare Parts List, dated 15 March 1971. These values are as follows:

Card, digital	$475.00
Card, electromechanical	$425.00
Card, analog	$550.00
Module	$265.00

It is recognized that the above values reflect current price estimates, and that such prices are subject to labor and material cost fluctuations over the 10-year period being considered. They are, however, predicated upon a low volume production situation, as is generally the case with follow-on spares orders.

Since both the DAF and RAF candidates are subject to labor and material cost fluctuations, this analysis considers the effects of these fluctuations to be equal for each candidate. On this basis, all cost computations in this and subsequent sections are in terms of currently defined values.

SN 6(1) lists 10-year DAF costs for each subassembly type as a function of varying equipment quantities. The costs shown are computed, based on the failure rate data of SN 3(3) and the average subassembly prices discussed above. Fractional failure quantities were rounded to the next higher integer as part of the computation.

SUB-NOTE 6(1) 10-Year DAF Subassembly Cost

	COST ($ x 1K)			
	1 Set	100 Sets	300 Sets	500 Sets
Card, Digital	9.025	878.750	2636.250	4393.750
Card, Electromechanical	0.850	44.200	131.750	217.725
Card, Analog	1.650	124.300	372.900	621.500
Module	1.325	125.610	376.300	627.255
	12.850	1172.860	3517.200	5860.230

7. RAF COST FACTORS

A number of various costs contribute to the overall expense incurred when implementing a repair-at-failure (RAF) maintenance philosophy. These costs are of two basic types - recurring and nonrecurring. These costs and the manner in which they are computed for use by this analysis are discussed below.

7.1 Nonrecurring RAF Costs

Several nonrecurring costs are attributable to the RAF candidate. These include design, production, and support of depot or SRA AGE, entry and administration of new lines in the Federal Supply System, and initial filling of the repair pipeline.

7.1.1 Depot or SRA Repair AGE

The repair of failed Multiplexer Set cards and modules includes the tasks of fault detection, isolation, and repair verification or checkout. It is considered that certain items of special and/or conventional AGE will be required in support of these tasks. Additionally, the cost of providing life cycle support for this AGE is attributable to the RAF candidate and must therefore be estimated.

a. AGE Development and Acquisition Cost

Engineering and development cost estimates assume that a single, multifunction test set will be provided rather than individual test sets for each card or module category. This test set is comprised of the following items:

Digital printed circuit boards	- 18
Analog printed circuit boards	- 4
Power supply	- 1
Tape reader	- 1
Case/cabinet	- 1
Front panel w/controls	- 1
Card file and wiring plans	- 1

Electrical components number approximately 660 integrated circuits plus miscellaneous indicators and controls.

The estimated cost for this test set is as follows:

Engineering and test, to include preparation of tape programs and test procedures	$230.6K
Components and assembly	20.1K
	250.7K

Were this cost to be divided among the various items to be tested, each category would represent approximately the following cost:

Digital cards	$205.6K
Electromechanical and analog cards	35.1K
Modules	10.0K
	$250.7K

Fault isolation and checkout of modules and electromechanical and analog cards will also require ancillary items of standard and common test equipment. Total AGE cost for these items is estimated as follows:

(1) Module test function

Contribution to special AGE	$10.0K
Signal generator	1.0K
Oscilloscope	2.5K
	$13.5K

(2) E/M-analog card test function

Contribution to special AGE	$35.1K
Frequency counter	5.3K
Oscilloscope	2.5K
	$42.9K

Considering both contribution to special AGE and ancillary standard AGE costs, estimated acquisition cost for fault isolation and checkout AGE for Multiplexer Set cards and modules may be summarized as follows:

Digital cards	$205.6K
E/M-analog cards	42.9K
Modules	13.5K
	$262.0K

b. AGE Support Cost

The items of special and standard AGE required in the depot or SRA repair process must be provided with maintenance and logistical support over the Multiplexer Set life cycle. This support includes the following cost contributors:

- Technical manuals
- FSN assignment and administration
- Spares
- Corrective maintenance
- Preventive maintenance

Subsequent paragraphs address each of the above cost contributors. It should be noted that because the AGE being supported is defined largely in conceptual terms, AGE support cost estimates are heavily based upon experience and judgment rather than upon detailed analysis.

The content of a technical manual supporting the special test set is expected to be approximately as follows:

Text and tabular material	-	140 pages
Illustrations, test set	-	60 pages
Illustrations, reparable item	-	50 pages
Total	-	250 pages

Reference 1 (Para 10) provides a cost factor of $150.00 per page of new technical data. On this basis, estimated manual cost is $37,500.

The quantity of Federal Stock Numbers (FSN's) which must be assigned in support of the test set is estimated to be as follows:

Printed circuit cards	-	14
Overall test set	-	1
Miscellaneous components	-	10
Total	-	25

Reference 1 (Para 10) establishes the following cost factors for entering and maintaining new assembly and part level items in the supply system:

(1) Part	
Enter	$ 171.01
Maintain 9 years	3381.12
Total (part)	$ 3552.13
(2) Assembly	
Enter	$ 233.09
Maintain 9 years	5287.41
Total (assembly)	$ 5520.50

Based upon these values, total FSN-related cost for the test set is $118,330.

Spares cost in support of special and standard ACE is estimated to be 25 percent of initial acquisition cost (exclusive of development expense). On this basis, AGE spares cost is as follows:

Special AGE (0.25 x $20.1K)	$5,030.00
Standard AGE (0.25 x $11.3K)	2,825.00
Total (spares)	$7,855.00

Corrective and preventive AGE maintenance costs are predicated upon the following:

- Standard test equipment is calibrated quarterly over the 10-year life cycle.
- The combination of standard and special AGE will require corrective maintenance once each quarter.
- Each preventive or corrective maintenance task is accomplished in an average of 2 manhours.

Based upon the above, and the $10.00 per hour labor rate provided by Reference 1 (Para 10), the cost for providing corrective and preventive AGE maintenance support is:

Preventive maintenance	$3200.00
Corrective maintenance	800.00
Total (maintenance)	$4000.00

Total AGE support cost, as identified in the preceding paragraphs, is summarized below:

Technical manuals	$ 37,500.00
FSN administration	118,330.00
Spares	7,855.00
Maintenance	4,000.00
Total (AGE support)	$167,685.00

As determined in Subparagraph e above, the estimated cost to develop/acquire AGE was $262.0 K, distributed as follows:

	$(x 1K)	%
Digital cards	205.6	78.5
E/M-analog cards	42.9	16.4
Modules	13.5	5.1
	$262.0	100.0

Since the bulk of AGE support cost is nonrecurring, it has been assumed that the total AGE support cost is distributed in a similar manner. On this basis, the total AGE support cost of $167.7 is attributable to the various reparable item categories as follows:

	$(x 1K)
Digital cards	131.6
E/M-analog cards	27.5
Modules	8.6
	$167.7

7.1.2 Depot Repair Pipeline Cost

With the RAF candidate, a cost is incurred for initial filling of the depot repair pipeline. This pipeline, depicted in SN 7.1.2(1), is the duration for which a failed item is unavailable to the user through his supply system. Pipeline duration is controlled by factors such as transportation time from user to SRA or depot, and time required for the SRA or depot to repair the item and return it to the supply system.

The complete repair/resupply loop also includes the time required for the user to order and obtain a replacement item from the supply system. Since the order and shipping time is equal for RAF and DAF candidates, it is not considered in the pipeline cost computation.

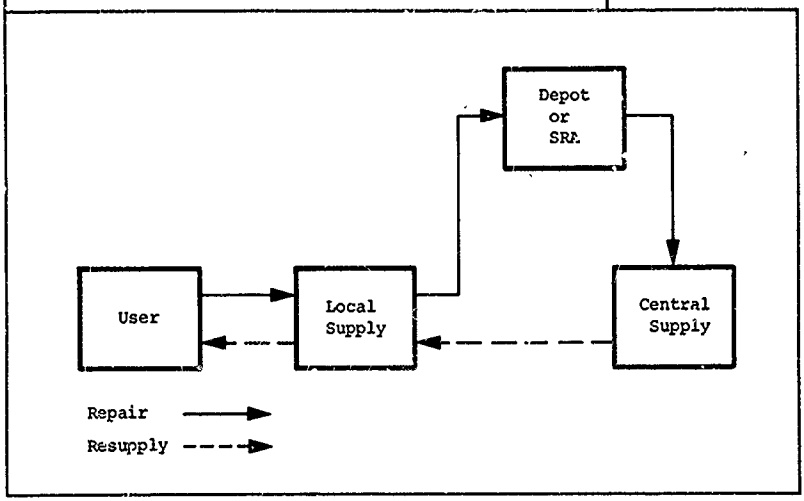
The cost for filling the repair pipeline is dependent upon the following factors:

- Failure rate of the returned items
- Quantity of equipments supported
- Cost of the returned items
- Length of the pipeline

Reference 1 (Para 10) provides typical lengths for CONUS and OS pipelines of 1.5 and 3.0 months, respectively. Using these pipeline intervals and the failure rate data listed in SN 3(3), the quantity of items required in the pipeline was computed. These data are listed in SN 7.1.2(2) for quantities of Multiplexer Set equipments varying between one and 500. It should be noted that deployed equipments have been assumed to be equally divided between OS and CONUS locations.

SN 7.1.2(3) lists the resulting pipeline cost for these equipment quantities, based upon the item cost data of Paragraph 6 and the item quantity data of SN 7.1.2(2). The data shown in SN 7.1.2(2) is rounded to the next higher integer where fractional quantities are involved.

SUB-NOTE 7.1.2(1) Depot or SRA Repair and Resupply Lines



SUB-NOTE 7.1.2(2) Items Required in Repair Pipeline for Varying Multiplexer Set Equipment Quantities

A. CONUS

Item	Qty/100 Sets	Qty/300 Sets	Qty/500 Sets
1. Module	3	9	15
2. Board, analog	2	5	8
3. Board, digital	12	35	58
4. Board, electrical/ mechanical	1	2	4
	18	51	85

B. OS

Item	Qty/100 Sets	Qty/300 Sets	Qty/500 Sets
1. Module	6	18	30
2. Board, analog	3	9	15
3. Board, digital	24	70	116
4. Board, electrical/ mechanical	2	4	7
	35	101	168

SUB-NOTE 7.1.2(3) Repair Pipeline Cost for Varying Multiplexer Set Equipment Quantities

	COST ($ x 1K)			
	1 Set	100 Sets	300 Sets	500 Sets
1. Card, digital	0.475	17.100	49.875	82.650
2. Card, electrical/mechanical	0.425	1.275	2.550	4.675
3. Card, analog	0.550	2.750	7.700	12.650
4. Module	0.265	2.385	7.155	11.925
	1.715	23.510	67.280	111.900

7.1.3 Supply Administration Cost

Printed circuit card and module repair requires that discrete component parts comprising these items be available via the Federal Supply System.

Integrated circuits used within the Multiplexer Set are largely of the transistor-transistor logic (TTL) family produced by Fairchild, Incorporated. Roughly 30 percent of these devices are within the medium scale integrated circuit (MSI) category, and as such are relatively new to the industry.

In certain Multiplexer Set circuits, higher speed devices are used. Again, these devices have been available for a relatively short period.

The line interface (driver and receiver) modules use thick film hybrid circuits especially designed for Multiplexer Set application. In the case of these devices, and other discrete module components such as precision resistors and pin/socket sets, it is doubtful that Federal Stock Numbers now exist or will exist when module repair activity is initiated.

On the other hand, with the increasing use of MSI TTL, it is difficult to determine which such devices will have entered the Federal Supply System by the time they are demanded for Multiplexer Set board repair.

For purposes of this analysis, a somewhat cursory check of Federal Supply System documentation was made. This check indicated that many of the more conventional (non-MSI) TTL integrated circuits being used in the Multiplexer Set have assigned FSN's. While this would indicate an intent on the part of the military to keep the supply system abreast of currently used devices, it is difficult to accurately define the situation to be experienced during the Multiplexer Set support interval.

It therefore appears that a best estimate of the line item quantity to be assigned FSN's solely for Multiplexer Set repair support is appropriate. The estimate used in this analysis is as follows:

Digital integrated circuits	-	10
Analog components	-	5
Module components	-	10
		25

Reference 1 (Para 1D) establishes a cost factor for the introduction of a new piece part line item to the Federal Supply System, and one for yearly administrative maintenance once entry has been made. These cost factors are as follows:

FSN assignment	-	$171.01
Yearly administration	-	375.68

The year administration cost is applied each year of the equipment life cycle, except for the year in which the line item is initially entered. On this basis, the estimated Multiplexer Set supply entry and administrative cost is as follows:

Digital integrated circuits (on printed circuit boards)	$35,521.30
Analog components (on printed circuit boards)	17,760.65
Module components	35,521.30
	$88,803.25

7.2 Recurring RAF Costs

7.2.1 Packaging and Transportation Cost

Failed items returned to the depot or SRA facility are packaged by the local (on-base) supply activity, transported to the repair facility, and repackaged by the repair facility for reinsertion into the supply system. Such effort incurs packaging and transportation expense at rates dependent upon the geographical location at which the reparable item was generated.

For purposes of this analysis, the nonpackaged weight of a typical Multiplexer Set board or module is estimated at 1 pound. On this basis, reference 1 (Para 10) provides the following cost data:

a. Labor cost for packaging
   - CONUS - $0.1868 per pound
   - OS - $0.2331 per pound

b. Material cost for packaging
   - CONUS - $0.0497 per pound
   - OS - $0.2331 per pound

c. Ratio, packaged to unpackaged weight
   - CONUS - 1.285
   - OS - 1.436

d. Transportation cost
   - CONUS TO SRA - $0.0410 per pound
   - OS to SRA - $0.4309 per pound

Based on the above, the packaging and transportation cost incurred with a reparable board or module generated at a CONUS location is as follows:

Labor, on-base packaging	$0.1868
Material, on-base packaging	0.0497
Transportation, base to SRA	0.0527
Labor, SRA packaging	0.1868
Material, SRA packaging	0.0497
	$0.5257

Similarly, packaging and transportation cost for a reparable generated at an OS location is as follows:

Labor, on-base packaging	$0.2331
Material, on-base packaging	0.2331
Transportation, base to SRA	0.6188
Labor, SRA packaging	0.2331
Material, SRA packaging	0.2331
	$1.5512

Each generated reparable will then incur the following packaging and transportation cost:

CONUS generated reparable	$0.53
OS generated reparable	$1.55

Since it has been assumed that the fielded Multiplexer Set equipments are evenly divided between CONUS and OS locations, the average packaging and transportation cost per repair action can be expressed as:

$$\frac{\$1.55 + \$0.53}{2} = \$1.04$$

Using the failure rate data from SN 3(3), SN 7.2.1(1) lists 10-year packaging and transportation costs for Multiplexer Set equipment quantities between one and 500. Fractional failure quantities are rounded to the next higher integer for purposes of this computation.

7.2.2 Depot or SRA Repair Labor

Another cost incurred with the RAF candidate is that of depot or SRA repair labor. This labor is expended in performing such tasks as receiving, documenting, and inspecting the failed item, as well as the normally encountered isolation, repair, and repair verification tasks.

SUB-NOTE 7.2.1(1) 10-Year Packaging and Transportation Costs for Varying Multiplexer Set Equipment Quantities

	COST ($ x 1K)			
	1 Set	100 Sets	300 Sets	500 Sets
1. Card, digital	0.020	1.924	5.772	9.620
2. Card, electrical/ mechanical	0.002	0.108	0.322	0.538
3. Card, analog	0.003	0.235	0.705	1.175
4. Module	0.005	0.493	1.477	2.462
	0.030	2.760	8.276	13.795

SN 7.2.2(1) depicts a typical failed item repair sequence. To each step of the flow sequence are assigned estimated completion times in minutes. From SN 7.2.2(1), it can be seen that the overall repair sequence is estimated to require an average of 80 minutes, or 1-1/3 (1.33) hours per item.

Reference 1 (para 10) provides a standard depot labor rate of $10.00 per man-hour. Using this rate, the average labor cost is $13.30 per item repair action. This value is used for purposes of estimating total repair labor cost for the RAF candidate.

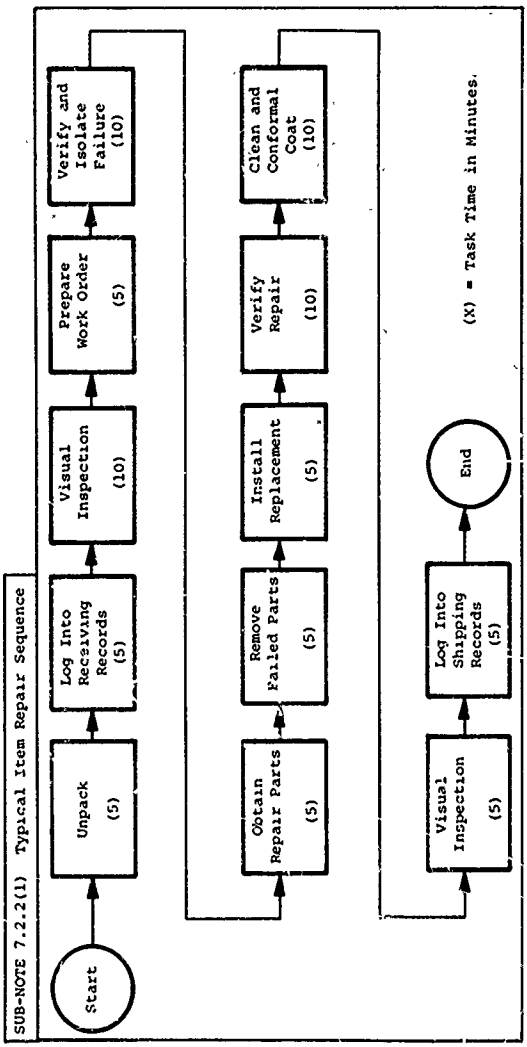
SN 7.2.2(2) lists 10-year repair labor costs estimated for the various items to be repaired. These costs are shown for varying quantities of fielded Multiplexer Set equipments. Quantities of repair actions used in computing the costs shown in SN 7.2.2(2) are based upon the failure rate data of SN 3(1).

It should be noted that repair labor costs have been computed on the basis of active repair times only, and consider any such labor to be available from existing manpower complements.

7.2.3 Depot or SRA Repair Part Cost

Reference 2 (Para 10) provides a model constant of three replacement parts per repair action. This same factor is quoted by Reference 3 (Para 10). However, since this factor is predicated upon data collected prior to early 1963, it is considered likely that such data is related to electron tube or discrete part solid state equipments. Recent experience with equipments comprised of integrated circuits indicates that repair typically involves replacement of only one such device. Part cost estimates used in this analysis are therefore based upon a single part replacement per repair action.

A review of integrated circuit component prices currently listed in industrial catalogs indicates an average device cost of approximately $7.50. This cost is predicated upon procurement quantities of 100 or less per device type and is for military grade, ceramic devices. Using a replacement part cost of


SUB-NOTE 7.2.2(1) Typical Item Repair Sequence
Start
Unpack (5)
Log Into Receiving Records (5)
Visual Inspection (10)
Prepare Work Order (5)
Verify and Isolate Failure (10)
Obtain Repair Parts (5)
Remove Failed Parts (5)
Install Replacement (5)
Verify Repair (10)
Clean and Conformal Coat (10)
Visual Inspection (5)
Log Into Shipping Records (5)
End
(X) = Task Time in Minutes.

$7.50 per repair action, SN 7.2.3(1) lists total repair part costs for quantities of multiplexer sets between one and 500.

SUB-NOTE 7.2.2(2) 10-Year Depot or SRA Repair Labor Costs for Varying Multiplexer Set Equipment Quantities

	$ Cost/100 Sets	$ Cost/300 Sets	$ Cost/500 Sets
1. Modules	6, 1.90	18,884.70	31,474.50
2. Board, analog	3,00 .50	9.013.50	15,022.50
3. Board, digital	24,603.70	73,811.10	123,018.50
4. Board, electrical/ mechanical	1,373.90	4,121.70	6,869.50
	35,277.00	105,831.00	176,385.00

SUB-NOTE 7.2.3(1) 10-Year Repair Part Cost

	Cost ($ x 1)			
	1 Set	100 Sets	300 Sets	500 Sets
1. Digital cards	143	14,300	42,900	71,500
2. E/M-analog cards	23	2,300	6,900	11,500
3. Modules	38	3,800	10,650	19,000
	204	20,400	60,450	102,000

8. DAF/RAF COST COMPARISON

Paragraphs 6 and 7 have identified and discussed costs associated with DAF and RAF candidates, respectively. This paragraph presents a comparison of these costs as a function of the quantity of Multiplexer Set equipments being supported.

As shown in Paragraph 6, the total DAF cost is essentially that of replacing failed items which have been discarded. The total cost for the RAF candidate is comprised of a number of individual recurring and nonrecurring costs. Among these are the following:

a. Nonrecurring
   - Repair AGE
   - Repair AGE support
   - Repair pipeline
   - FSN administration

b. Recurring
   - Packaging and transportation
   - Repair labor
   - Repair parts

SN 8(1), SN 8(2), and SN 8(3) summarize DAF and RAF costs developed in Paragraphs 6 and 7 for modules, digital cards, and E/M-analog cards respectively.

SN 8(4) graphically depicts the data contained in SN 8(1) through SN 8(3) and illustrates the DAF/RAF cost crossover for each category. From SN 8(4), it can be seen that the repair at failure is most economical for all item categories once approximately 60 Multiplexer Set equipments are being supported.

SUB-NOTE 8(1) DAF/RAF Cost Summary - Modules

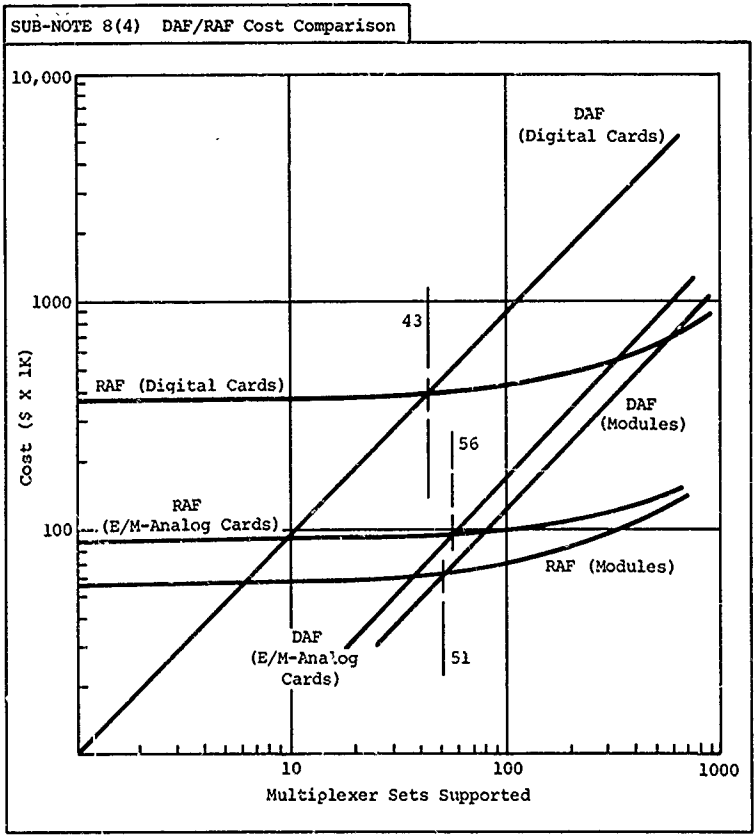
	COST ($ x 1K)			
	1 Set	100 Sets	300 Sets	500 Sets
A. REPAIR-AT-FAILURE COST				
Nonrecurring				
AGE	13.5	13.5	13.5	13.5
AGE Support	8.6	8.6	8.6	8.6
Pipeline	0.3	2.4	7.2	11.9
FSN Administration	35.5	35.5	35.5	35.5
Subtotal	57.9	60.0	64.8	69.5
Recurring				
Pack and ship	Neg.	0.5	1.5	2.5
Labor	Neg.	6.3	18.9	31.5
Parts	Neg.	3.8	10.7	19.0
Subtotal	Neg.	10.6	31.1	53.0
RAF total	57.9	70.6	95.9	122.5
B. DISCARD-AT-FAILURE COST	1.3	125.6	376.3	627.3
DAF total	1.3	125.6	376.3	627.3

SUB-NOTE 8(2) DAF/RAF Cost Summary - Digital Cards

	COST ($ x 1K)			
	1 Set	100 Sets	300 Sets	500 Sets
A. REPAIR-AT-FAILURE COST				
Nonrecurring				
AGE	205.6	205.6	205.6	205.6
AGE support	131.6	131.6	131.6	131.6
Pipeline	0.5	17.1	49.9	82.7
FSN administration	35.5	35.5	35.5	35.5
Subtotal	373.2	389.8	422.6	455.4
Recurring				
Pack and ship	Neg.	1.9	5.8	9.6
Labor	Neg.	24.6	73.8	123.0
Parts	0.2	14.3	42.9	71.5
Subtotal	0.2	40.8	122.5	204.1
RAF total	373.4	430.6	545.1	659.5
B. DISCARD-AT-FAILURE COST	9.0	878.8	2636.3	4393.8
DAF total	9.0	878.8	2636.3	4393.8

SUB-NOTE 8(3) DAF/RAF Cost Summary - E/M-Analog Cards

	COST ($ x 1K)			
	1 Set	100 Sets	300 Sets	500 Sets
A. REPAIR-AT-FAILURE COST				
Nonrecurring				
AGE	42.9	42.9	42.9	42.9
AGE support	27.5	27.5	27.5	27.5
Pipeline	1.0	4.0	10.3	17.3
FSN administration	17.8	17.8	17.8	17.8
Subtotal	89.2	92.2	98.5	105.5
Recurring				
Pack and ship	Neg.	0.3	1.0	1.7
Labor	Neg.	4.4	13.1	21.9
Parts	Neg.	2.3	6.9	11.5
Subtotal	Neg.	7.0	21.0	35.1
RAF total	89.2	99.2	119.5	140.6
B. DISCARD-AT-FAILURE COST	2.5	168.5	504.7	839.2
DAF total	2.5	168.5	504.7	839.2


SUB-NOTE 8(4) DAF/RAF Cost Comparison
10,000
1000
100
Cost ($ X 1K)
DAF
(Digital Cards)
43
RAF (Digital Cards)
DAF
(Modules)
56
RAF
(E/M-Analog Cards)
RAF (Modules)
DAF
(E/M-Analog
Cards)
51
10
100
1000
Multiplexer Sets Supported

9. CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of this analysis, it can be concluded that depot or SRA repair of failed Multiplexer Set cards and modules is more economical than discard at failure. This is provided, of course, that the quantity of supported Multiplexer Sets exceeds approximately 60.

The largest potential source of error encountered in the analysis is considered to be related to the manner in which long-term labor and material cost fluctuations are treated. As noted in Paragraph 6, all costs are computed on the basis of current estimates and are considered to fluctuate equally for both DAF and RAF candidates. It can be argued that such an approach is invalid on the basis that the DAF candidate results in larger dollar expenditures, and is therefore more subject to inflationary trends. However, since the RAF candidate is clearly preferable from a total cost standpoint, any inequity associated with the potentially larger long-term DAF cost fluctuation becomes irrelevant.

As for other unidentified error sources which may exist, it should be noted that the cost differential between DAF and RAF candidates increases sharply as a function of the quantity of Multiplexer Set equipments being supported. At a quantity of 100 sets supported, this differential climbs to nearly $600,000, and at 500 sets, becomes approximately $5 million.

It becomes difficult to envision errors or overlooked cost factors which, when considered, could offset such a significant margin.

It is therefore recommended that if a total of 60 or more Multiplexer Set equipments are to be operationally supported, the support concept for failed cards and modules be predicated upon their repair and reuse.

10. REFERENCES

1. AFLCM/AFSCM 375-6, Optimum Repair Level Analysis, dated 20 May 1968.
2. RADC-TR-68-187, Maintainability of Microcircuit Equipment, dated September 1968
3. AD 455102, Economic Decision Criteria for Repair Versus Throwaway Maintenance, 1963-1964
4. CER-RM-003-2, Reliability and Maintainability Allocations, Assessment and Analysis Report (Revision 3) for Multiplexer Set AN/GSC-24(V), dated 26 February 1971

CHAPTER 8

SPECIAL MAINTAINABILITY ANALYSIS

This chapter contains a description of the special maintainability analysis task.

CHAPTER 8 SPECIAL MAINTAINABILITY ANALYSIS

SECTION 8A - DESCRIPTION

Design Note 8A1 - Special Analysis

SECTION 8A

DESCRIPTION

This section contains a description of the special maintainability analysis task. To describe this task, examples of different types of analysis performed on the Multiplexer Set are presented.

SECTION 8A DESCRIPTION

DESIGN NOTE 8A1 - SPECIAL ANALYSIS

1. GENERAL

2. SPECIAL MAINTAINABILITY EXAMPLES

2.1 Example 1, Diagnostic Effectiveness

2.2 Example 2, Access Provisions

2.3 Example 3, Mechanical Interference

2.4 Example 4, Diagnostic Ambiguity

2.5 Example 5, Test Equipment Selection

2.5(1) Ratio, Counter to Measured Signal Accuracy, for Varying Calibration Intervals

2.6 Example 6, On-Line Maintenance

2.6.1 Areas of On-Line Maintenance Potential

2.6.2 Investigation Tasks

2.6.3 Analysis

2.6.3(1) RCB/SB Initiate

2.6.4 Summary of On-Line Maintenance

2.6.4(1) On-Line Maintenance Performance Summary

DESIGN NOTE 8A1 SPECIAL ANALYSIS

1. GENERAL

The term "special maintainability analysis" refers to those analytical efforts which are peculiar to the particular development process at hand. This is as opposed to those analytical tasks such as allocations, predictions, and trade-offs which are typically common to all maintainability programs.

Special maintainability analyses may address form, fit, function, or cost, either individually or in combinations, as the situation dictates. With such a wide range of potential subject matter, it becomes difficult if not impossible to provide firm guidance in the form of guidelines and methodology. Rather, emphasis is given to illustrative examples.

2. SPECIAL MAINTAINABILITY ANALYSIS EXAMPLES

2.1 Example 1, Diagnostic Effectiveness

In the Chapter 1 discussion pertaining to formulation of maintainability and maintenance-related constraints, we addressed derivation of the mean corrective time ($\overline{M}_{ct}$) requirement for the Multiplexer Set equipment. This value was 0.2 hour, or 12.0 minutes. It was also established that attainment of this constraint, with the skill levels expected to be available in the user's organization, would necessitate the incorporation of fault localization and isolation aids within the Multiplexer Set design.

Recognizing that such aids have certain inherent limitations, we must ascertain how effective these aids must be, and determine if the required effectiveness is feasible to attain. Effectiveness is defined as that percentage of the total multiplexer failures which are successfully treated by the integral diagnostic aids.

The first step in this special maintainability analysis entails determining the average corrective maintenance task time if both effective diagnostic aids were provided and the diagnosis were left to conventional "scope and schematic" processes.

Based upon the use of one or more of the prediction methods discussed in Chapter 13, let us assume that tasks accomplished using integral diagnostic aids can be completed in an average of 5.0 minutes, and those entailing conventional troubleshooting processes in 45.0 minutes.

If we let X represent the percentage of faults effectively treated by the diagnostic aids (expressed as a probability), and 1-X as the percentage of faults conventionally diagnosed, then:

$$(X)\ (5.0) + (1\text{-}X\ (45.0) = 12.0$$

$$X = 0.925$$

or 92.5 percent.

Thus the diagnostic aids to be incorporated within the Multiplexer Set design must be 92.5 percent effective to enable compliance with the 12.0-minute $\overline{M}_{ct}$ constraints.

A detailed discussion with the electrical engineers designing the Multiplexer Set establishes that approximately 95 percent of all Multiplexer Set failures could be effectively treated by integral diagnostic aids. Since the required effectiveness of 92.5 percent is less than this value, the requirement appears feasible and is undertaken as a working design constraint.

2.2 Example 2, Access Provisions

Implicit in attaining diagnostically aided Multiplexer Set task times averaging 5.0 minutes, is the requirement for rapid access to the equipment internals. For this reason, and considering other design requirements pertaining to shock and vibration, the front access cover of the Multiplexer Set is secured by fast-lead quick release screw devices.

Using a prototype Multiplexer Set chassis as a vehicle, an assessment of accessing ease and speed was conducted. This assessment indicated a fastening device problem having significant maintainability impact.

The threaded body of the fast-lead device was of a length precluding complete independent release of an individual fastener while other fasteners remained engaged. This therefore required that all door fasteners be released (or tightened) in a sequential fashion, and that several cycles of this sequence be repeated to accomplish door opening (or closing). With this arrangement, door opening or closing required approximately 4 to 5 minutes, and thus has unacceptable impact upon equipment maintenance time.

The manufacturer of the fastener produces a variety of different fast-lead screw types which interface with the fastener receptacles installed in the Multiplexer Set chassis.

Of these, one exhibits thread body dimensions permitting complete independent fastener release or engagement. Several samples of the new device were obtained and tested for proper performance. With the revised fastener type, access door opening or closure can be accomplished within approximately 1 minute. This is fully consistent with previously predicted values, and is considered quite acceptable for the Multiplexer Set design.

On this basis, engineering documentation will be revised to reflect use of this alternate fastener, thus resolving the problem.

2.3 Example 3, Mechanical Interference

A mechanical interference problem between the chassis structure and the harness connecting to the equipment side of the input power filter assemblies was observed. This interference precluded filter replacement from the rear of the chassis, thus requiring wiring plane removal as part of the filter replacement process. This problem was resolved by enlargement of the chassis clearance holes through which the filter wiring harness is routed. With this change, either of the filter assemblies may be extended a sufficient distance from the chassis rear surface to permit separation or connection of the filter electrical terminals.

This revision has been incorporated in the Multiplexer Set design, and has been demonstrated to have corrected the problem.

2.4 Example 4, Diagnostic Ambiguity

The diagnostic implementation for the Multiplexer Set rate comparison buffer (RCB) is unable to distinguish between an input timing out-of-tolerance condition and certain RCB failure modes. In certain cases, therefore, an out-of-tolerance display was also accompanied by one or more malfunction indications.

Special analysis of this problem indicated a potential resolution. In the RCB, the front panel display of an apparent out-of-tolerance condition may be momentarily withheld while the RCB diagnostic automatically performs a predetermined self-test routine. This routine inserts a known in-tolerance timing reference into the elastic store logic, instead of the normal input timing. If the detected out-of-tolerance condition clears during the test interval, the input timing signal is known to be out of tolerance, and the panel display is allowed to activate. If the out-of-tolerance condition continues to be detected during the self-test routine, an RCB malfunction is known to exist, and is so displayed on the front panel. The worst case time to complete the self-test routine is approximately 250 milliseconds.

Further analysis by the electrical engineer indicates that this potential "fix" can be implemented with negligible impact on design complexity. On this basis, a preliminary redesign and a breadboard test have been planned.

2.5 Example 5, Test Equipment Selection

The fundamental output frequency of the Multiplexer Set reference timing source is 9.8304×10^6 Hz. In accordance with the Multiplexer Set design specification, this source is adjustable to 1 part in 10^7, with a long-term stability of 1 part in 10^6 per 30 days. The phase lock loop reference timing source in the Multiplexer Set operates at a fundamental frequency of 1.843×10^6 Hz, and exhibits adjustment and stability characteristics identical to those of the Multiplexer Set reference timer.

The drift characteristics of these timing sources, together with the minimum acceptable inaccuracy of 1 part per 10^6 per 30 days, require that they be periodically calibrated and readjusted as required.

A recognized standard for the calibration of such signals is the use of a test instrument (frequency counter) having an accuracy four times that of the signal being calibrated. In the Multiplexer Set case, this is one-fourth of 1 part in 10^7, or 2.5 parts in 10^8. Lower accuracy ratios can be used, if necessary, but should not be allowed to go lower than 2 to 1.

Because the frequency counter being used must itself be calibrated, it is desirable that its calibration interval be as long as possible to reduce workload upon the local Precision Measuring Equipment Laboratory (PMEL).

For purposes of this analysis, a test instrument calibration interval of 90 days was established as a goal.

Other than initial calibration accuracy and short-term instability, the primary factor dictating the calibration interval is time base drift due to crystal aging characteristics. If a 90-day calibration interval is assumed, and calibration accuracy ignored momentarily, the required aging characteristics for a 4:1 accuracy ratio must be:

$$(90)\ (x) = 2.5$$

$$x = 0.0277$$

where x is the aging rate per day in parts per 10^8.

Similarly, if the accuracy ratio is reduced to 2:1, the required aging rate must not exceed

$$(90)\ (x) = 5.0$$

$$x = 0.0555 \text{ parts per } 10^8 \text{ per day.}$$

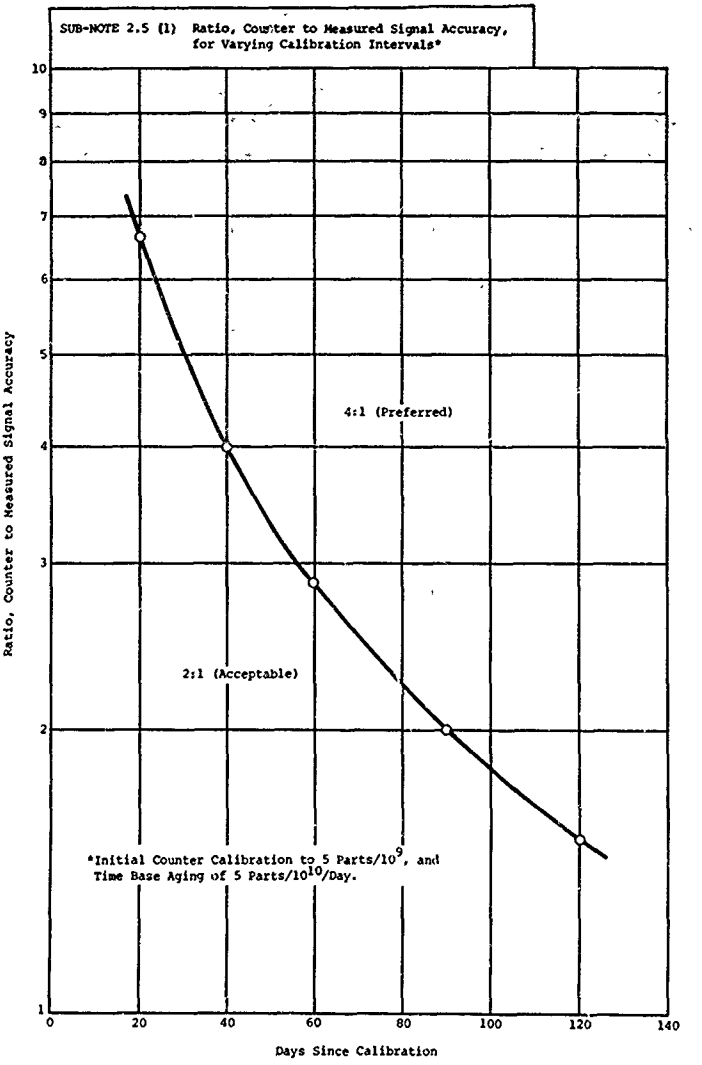
Based upon the above, drift of the test instrument time base due to crystal aging must be no greater than 5.6 parts per 10^{10} per day. An aging rate no greater than 2.8 parts per 10^{10} per day is required if the 4:1 accuracy ratio is to be maintained.

A review of MIL-HDBK-300A (USAF) did not reveal a listing for an instrument possessing the required aging drift characteristics. Further investigation of data supplied by commercial instrument manufacturers indicates the availability of a frequency counter that appears compatible with the Multiplexer Set application.

The frequency counter measures input signals at frequencies between 0 and 50 x 10^6 Hz at an accuracy of its time base $\pm$ 1 count. The counter time base (internal) operates at a frequency of 5.0 x 10^6 Hz, and demonstrates an aging rate of less than 5.0 parts per 10^{10} per day. SN 2.5 (1) depicts this aging rate, in terms of the resulting counter calibration interval, for varying counter to measured signal accuracy ratios. From SN 2.5 (1) it can be seen that an acceptable (2:1) ratio can be maintained with counter calibration intervals of 90 days if initial counter calibration is to an accuracy of 5 parts in 10^9.

The frequency counter incorporates an eight-digit front panel readout display, thus negating the impact of the $\pm$ 1 count inherent inaccuracy when measuring signal frequencies of less than 10^7 Hz. The fundamental frequency of the Multiplexer Set reference timer, at 9.8304 x 10^6 Hz, thus falls within this category.

Based upon guidance received at the AGE Guidance Conference, the selected frequency counter should be operable from the same power sources as the Multiplexer Set. The manufacturer's data for the counter indicates that this feature is included.


SUB-NOTE 2.5 (1) Ratio, Counter to Measured Signal Accuracy, for Varying Calibration Intervals*
Ratio, Counter to Measured Signal Accuracy
10
9
8
7
6
5
4
3
2
1
4:1 (Preferred)
2:1 (Acceptable)
*Initial Counter Calibration to 5 Parts/10^9, and Time Base Aging of 5 Parts/10^10/Day.
0
20
40
60
80
100
120
140
Days Since Calibration

2.6 Example 6, On-Line Maintenance

Based upon reliability and maintainability discussion during the preliminary design review (PDR), the need for a high degree of Multiplexer Set availability was emphasized. This need is predicated upon the expected using environment, which may require continuous operation for extended periods without benefit of scheduled preventive maintenance downtime.

Of particular interest from an increased availability standpoint is the potential for performing a substantial amount of on-line corrective and preventive maintenance.

Simply stated, on-line maintenance involves the isolation and repair of failure in one part of the equipment while other parts remain powered and operating. The objective, of course, is to maintain overall system operation, even though some degradation may be unavoidable.

Some areas of the baseline Multiplexer Set design presently appear adaptable to on-line maintenance techniques. Others appear to offer this potential with certain design changes.

2.6.1 Areas of On-Line Maintenance Potential

a. Channel-Related Circuits and Logic

On-Line exchange of receiver/driver modules, and RCB/SB and TSRC/STRC cards should be a prime consideration for two reasons: (1) because of their quantity, they represent a large segment of overall Multiplexer Set failure rate; and (2) failure of a given channel represents equipment degradation rather than outage.

Several factors are pertinent when considering on-line maintenance of channel-related electronics:

- Equipment damage resulting from improper power removal/application sequences (particularly in line drivers).
- Reinitialization of logic timing.
- Power shorts caused by mechanical misalignment during replacement.

b. Power Supplies

The baseline design (two independent supplies with common sensing and switching) requires system power removal during replacement of a failed unit. Thus, from an availability standpoint, the only real advantage of such a redundant arrangement is a reduction of overall failure rate by withholding repair until both units have failed. This seems to defeat the potential of continuous operation which could be realized by repair of one failed unit while the other continues to enable equipment operation. As with the channel-related area, a prime factor relative to on-line replacement of failed power supplies is that of personnel and equipment safety.

c. Cooling Air Blowers

The baseline design uses two cooling air blowers. Failure of either blower is thermally detected by a common sensor. On-line replacement of failed blowers must consider personnel safety hazards caused by the 115-volt input power supply and the high-speed mechanical rotation of the fan.

Also to be considered is the potential damage to equipment caused by temperature increases when a blower fails or is depowered for maintenance purposes.

2.6.2 Investigation Tasks

In examining the Multiplexer Set on-line maintenance potential, certain specific tasks are performed.

a. Mechanical

(1) Determine if mechanical tolerances associated with module/chassis interface will permit inadvertent "cocking" of modules to the extent that adjacent edge-loaded connector foils can be shorted or otherwise misconnected to the chassis or to each other. Do the same for PC cards.

(2) Determine if sufficient space exists to incorporate nonsoldered, partial-turn electrical interconnection between chassis and cooling blowers.

(3) Determine the effect upon equipment operation when a blower has failed or is otherwise disabled.

(4) Examine space and positioning implications associated with similar disconnects between power supplies and loads and inputs.

(5) Determine equipment hazards associated with inadvertent touching of adjacent cards during power-on removal/replacement.

b. Circuits

(1) Examine equipment damage potential associated with random electrical disconnection and connection of driver and receiver modules with powered main chassis.

(2) Investigate the same for power supplies.

(3) Determine what damage potential exists when driver and receiver modules are operated with timing and data cables disconnected.

(4) Investigate the introduction of transients caused by card removal and insertion upon the replaced item and remaining equipment elements, including power sensing circuits.

c. Logic

(1) Establish equipment damage potential when power and signals are randomly removed and applied to logic cards.

(2) Investigate requirements for initialization in channel-related cards when replaced with power applied.

(3) Consider methods for resetting of diagnostic error latches and out-of-tolerance holding latches.

d. Other

Determine effect upon inherent availability when on-line maintenance capability is incorporated in selected areas.

2.6.3 Analysis

a. Assumptions

In the analysis of on-line maintenance implications, certain assumptions were made.

(1) The equipment configuration is the same as that upon which the current MTBF requirement is based.

(2) On-line maintenance of blowers considers the worst case room ambient temperature of 52°C and a 40°C Δ T in the driver/receiver module area.

(3) Blower investigation is based upon blower failure in module area.

(4) The failure rate distribution reflected in the prediction presented at the PDR will remain approximately unchanged, while the total failure rate will reduce to a point enabling attainment of the 2200-hour MTBF requirement.

b. Impact Upon Availability

(1) Channel-Related Electronics

When on-line maintenance of failures in channel-related areas is accomplished, only the failed channel is inoperative. The remaining 30 channels continue to process data in a normal manner. This effectively reduces the failure rate in the channel area to that associated with a single channel rather than with 31 channels.

Thus overall failure rate is effectively reduced to that associated with one channel plus common equipment. Without consideration for any additional hardware which may be required to enable on-line maintenance of the channel area, such a configuration yields an effective MTBF slightly in excess of 8000 hours.

NOTE: Subsequent sections will identify the requirement for certain added hardware to enable on-line maintenance of channel failures. This added hardware, which falls in the common electronics category, will lower the effective MTBF to approximately 7500 hours.

Because correction of failures in the channel area is presently an expedient process, reducing the effective failure rate in this area has an adverse effect upon $\bar{M}_{ct}$. Considering a ratio between predicted and required downtimes similar to that associated with the baseline design, on-line maintenance of channel failures will increase the $\bar{M}_{ct}$ to approximately 16.0 minutes.

An MTBF of 7500 hours and an $\bar{M}_{ct}$ of 16.0 minutes yields an availability of 0.999964. This is opposed to an availability of 0.999900 required of the baseline system.

(2) Power Supplies

On-line replacement of failed power supplies effectively reduces their downtime contribution to zero. If an on-line maintenance capability is provided in both the channel area and power supplies, effective MTBF is approximately 9000 hours. On-line power supply replacement represents little additional degradation of $\bar{M}_{ct}$, with the 16.0-minute value remaining applicable. Availability, when on-line maintenance of both channel area and power supplies is used, is approximately 0.999970.

(3) Cooling Air Blowers

Detailed life expectancy data for the baseline cooling air blowers is presently unavailable. However, preliminary discussions with representatives of the vendor's application engineering organization indicate a value of 20,000 to 30,000 hours to be reasonable. Bearing wearout is the primary failure mode, with random failure rate being essentially negligible.

Blower replacement due to wearout is considered in the category of preventive maintenance. However, due to the low expected replacement rate (once each 3.4 years at a 30,000-hour life), it is likely from a practical standpoint that scheduled replacement will be overlooked, forgotten, or ignored.

Based upon this factor, and the necessity for equipment shutdown when blower failure is encountered, some means for detecting and indicating blower degradation (before complete failure) would appear desirable.

c. Impact Upon Design

Incorporation of an on-line maintenance capability will necessitate certain modifications to the baseline design, primarily for reasons of personnel and equipment safety and logic initialization.

(1) Channel-Related Electronics

Presently, printed circuit cards are aligned with their respective connectors by 2-inch guides which are an integral part of the molded connector. The combination of mechanical tolerances and flexure of these guides at their upper end enables "cocking" of a printed circuit card during the installation process. The worst case magnitude of this cocking is such that misconnection of the card and its connector can occur before the card is fully seated. Stiffness of the guides at the lower (connector) end will preclude misconnection when the card is fully inserted.

To preclude inadvertent shorting of power, ground and signal interconnections during power-on card insertion, it is necessary to replace the present card guide arrangement with a design providing card alignment throughout the insertion process. This also entails addition of hardware for rigid support of the longer guide.

A similar alignment requirement exists if power-on line driver and receiver module exchange is contemplated. In the case of these modules, however, such alignment can be assured by the insertion of additional keying tabs in the chassis half of the module connector.

From an electrical standpoint, on-line exchange of items comprising the channel electronics area will necessitate the incorporation of a means for properly initializing input/output counters within the RCB and SB logic.

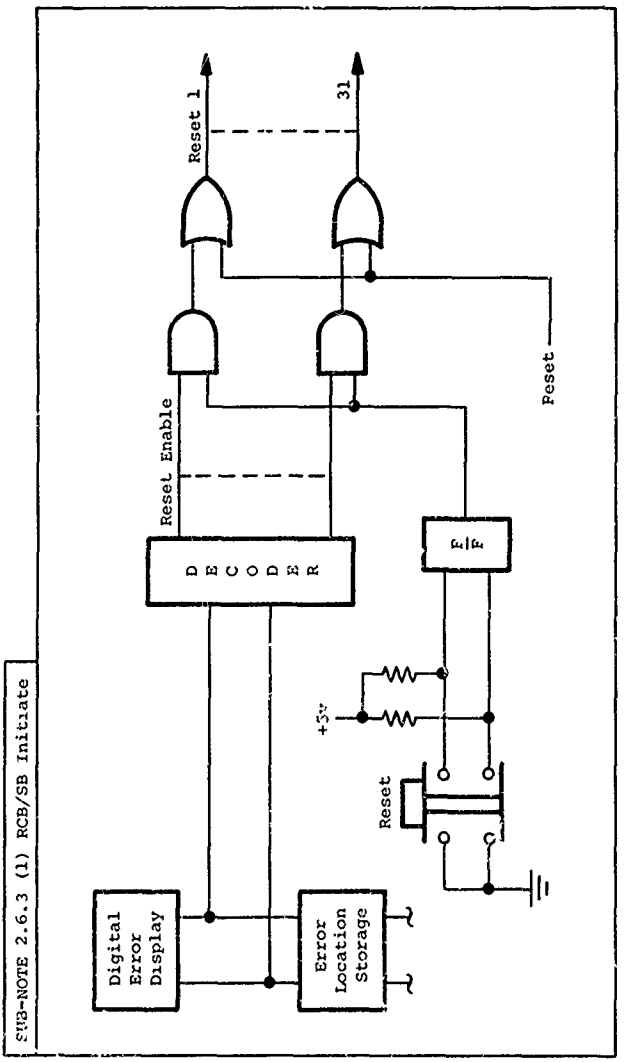
With the current design, this function is automatically performed upon application of primary power, which results in the generation of a power-on reset signal routed to all RCB's and SB's.

With on-line maintenance, generation of a similar reset signal must be accomplished. However, to preclude disrupting the operation of non-failed channels, the reset must be selectively applied only to the failed RCB or SB. One implementation of a design providing this function is depicted by SN 2.6.3 (1). With this design, the stored binary number representating of the fault location, normally applied to the front panel error display, is also routed to a binary-to-decimal decoder. Enabling the output of this decoder by the front panel ERROR RESET button allows a reinitializing pulse to be routed only to the channel associated with the stored error number. Storage latches (flip-flops) associated with the failed channel, which may assume an error state when the replacement item is installed, are thus readily reset by depressing the front panel RESET button.

Incorporation of the initialization design depicted by SN 2.6.3 (1) entails revision of present front panel and interconnecting cabling designs, as well as addition of channel number decoding logic. This logic could be collocated upon the remote alarm card, which presently has a sufficient amount of unused component mounting area.

(2) Power Supplies

The current design baseline uses two independent power supply units which may be alternately connected to the equipment load via common error sensing and switching circuits. Primary power is applied to both supplies via a 4PST front panel toggle switch. In normal operation, primary power is continuously applied to both the primary (on-line) and standby units. On-line replacement of a failed supply will require independent control of supply input power. This can be accomplished by replacing the present power switch with two switches of a 2PST configuration. For reasons of replacement expediency, input and output power supply terminals are exposed upon opening of the chassis access door. To preclude inadvertent contact with terminals of the active supply during on-line replacement of the failed unit, a protective cover is required. This may be a snap-on/off plastic design or other suitable design. Both personnel and equipment damage hazards dictate such protection.


SUB-NOTE 2.6.3 (1) RCB/SB Initiate
Reset 1
31
Reset Enable
Reset
D E C O D E R
+5v
Reset
Digital Error Display
Error Location Storage

(3) Cooling Air Blowers

Several factors influence the decision to perform on-line corrective maintenance of cooling air blowers. The design baseline uses a temperature sensing device for detection of failure in either blower. When equipment temperature exceeds the sensor actuation point, equipment operation may be impaired, and should be terminated by removal of input power. Due to the relatively high amount of power being dissipated, the operating temperature rise in the line driver area is approximately 40°C over room ambient temperature. Should failure of the cooling air blower in the module area occur, the temperature in this area will rise at a rate of approximately 1.8°C per minute. Thus, with a worst case room ambient temperature of 52°C, the temperature in the module area will reach 125°C approximately 18.3 minutes following blower failure. It is expected that proper equipment operation will terminate at or near this level.

Current predictions indicate that blower correction task time is approximately 25 minutes. While certain design changes could reduce this figure to within the 18-minute interval, the practical limitation is one of response time on the part of the operator or repairman. When delays in noting the occurrence of blower failure and/or in obtaining a replacement spare are considered, it is unlikely that blower failure correction can be effected before temperature limitations are exceeded. On this basis, on-line corrective maintenance of cooling air blowers is not recommended.

2.6.4 Summary of On-Line Maintenance

SN 2.6.4 (1) summarizes the effects upon MTBF, $\bar{M}_{ct}$, and availability resulting from incorporation of on-line maintenance provisions.

SUB-NOTE 2.6.4 (1) On-Line Maintenance Performance Summary

	MTBF (1)	$\bar{M}_{ct}$ (2)	Availability
1. Baseline Design	2200 (3)	12.0 (3)	0.999900
2. Channel Related Electronics	7500	16.0	0.999964
3. Channel Electronics and Power Supplies	9000	16.0	0.999970

(1) In hours (effective)

(2) In minutes

(3) Specified requirement

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